# COMPARISON OF STRUCTURAL SYSTEM FOR 300M TALL BUILDINGS IN HIGH WIND AREAS, SUCH AS KLCC, KUALA LUMPUR

FAUSO GULAMUSSEN SAMADE

CIVIL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS

JUNE 2010

# Comparison of Structural System for 300m Tall Buildings in High Wind Areas, Such as KLCC, Kuala Lumpur

By

Fauso Gulamussen Samade

Dissertation Submitted in partial fulfilment of

the requirement for the

Bachelor Degree of Engineering (Hons)

Civil Engineering

June 2010

Supervisor: Kalaikumar a/l Vallyutham

Co- Supervisor: Assoc. Prof. Dr. Nasir Shafiq

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

## CERTIFICATION OF APPROVAL

# Comparison of Structural System for 300m Tall Buildings in High Wind Areas, Such as KLCC, Kuala Lumpur

By

Fauso Gulamussen Samade

A project dissertation submitted to the

Civil Engineering Programme

Universiti Teknologi PETRONAS

In partial fulfilment of requirement for the

BACHELOR OF ENGINEERING (Hons)

CIVIL ENGINEERING

Approved by:

_______________________

Kalaikumar a/l Vallyutham

UNIVERSITI TEKNOLOGI PETRONAS
JUNE 2010

## CERTIFICATION OF ORIGINALITY

This certify that I am responsible for the work submitted in this project, that the original work is my own excepted as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Fauso Samade

FAUSO GULAMUSSEN SAMADE

**ABSTRACT**

The principal objective of this research study is to compare three different high-rise structural systems in terms of horizontal deflection and to determine the effective structural system under high wind speed in zones such as KLCC, Kuala Lumpur. Finding the best structural system for a 300m tall building under 35m/s wind speed, can be challenging in economical terms, the availability of materials, construction management, etc. Selection of software tool is critical in designing and also analysing the structure.

This analytical study was carried out based on design of three different structural systems with 300m height, 75 storeys using a software tool (CYPECAD 2007). Wind Load was calculated using NBR 6123(Brazil Wind Load Code, 1988). Analyses were done by changing the dimensions of the structural members and compare the results in terms of horizontal deflection and effectiveness.

The results from this research study showed that the Tube in Tube Structural System is most effective in resisting lateral deflection with its average deflection of 110.20mm, following by Frame Tube with average deflection of 142,89mm and lastly by Shear Wall Structural System with 227.38mm. Was also found that, bigger the member size of the structures smaller the lateral deflections, and that the Frame Tube is the most efficient in economical terms with an average amount of concrete $0.291m^3/m^2$ and steel quantity of $26.574kg/m^2$. In order to achieve more detailed results, more detailed design criteria should be taken into consideration.

## ACKNOWLEDGEMENT

First of all, I would like to take this opportunity to thank my Supervisor Kalaikumar a/l Vallyutham, and Co-Supervisor Assoc. Prof. Dr. Nasir Shafiq for the patient, support and guidance throughout the project. It has been such an honour to work and learn from such experienced professionals.

Secondly, I would like to thank my family especially to my father Gulamussen Zeinabibi Momade Samade and mother Rossana Abdul Kadir Issufo Samade, whom supported me all my entire life and always believed in me, not forgetting my sisters Irina Gulamussen Samade, and Yumara Gulamussen Samade.

Lastly, I would like to thank all those who contributed directly or indirectly for the success of this project and the success of my live.

"After the sacrifice, comes the glory..."
By Fauso Gulamussen Samade
Thank you ☺

## TABLE OF CONTENT

## LIST OF FIGURES

## LIST OF TABLES

# CHAPTER 1

# INTRODUCTION

## 1.1. Background Studies

Ancient tall structures such as the pyramids of Giza in Egypt, Mayan temples in Tikal, Guatemala are just few examples testifying to the human aspiration to build increasingly tall structures. These buildings are primarily solid structures serving as monuments rather than space enclosures. By contrast, contemporary tall structures are human habitats, conceived in response to rapid urbanization and population growth although the sheer audacity in their vertical scale may often give them the dubious title of monuments.

A tall building is not defined by its height or by the number of stories. A suggestion definition, then, might be "a building in which 'tallness' strongly influences planning, design, and use"; or "a building whose height creates different conditions in the design, construction, and use from those that exist in common buildings of a certain region and period". [1, page 6]

The design of tall buildings essentially involves a conceptual design, approximate analysis, preliminary design and optimization, to safely carry gravity and lateral loads. The design criteria for tall buildings are: Limits State Design, Gravity Loading, Wind Loading & effect, Earthquake Loading & Response, Sequential Loading, Strength and Stability, Drift Limitations, Stiffness, Human Comfort, Fire, Creep, Shrinkage, Foundation Settlement, Soil-Structure Interaction, Temperature Effects; however for this project we will just consider the Gravity Loading, the Wind Loading & Effect and the Drift Limitations. [1]

The structural system of a building is a three-dimensional complex assemblage of various combinations of interconnected structural elements. The primary function of the system is to carry effectively and safe all the loads acting of the building, and eventually transmit them to the foundation. In various types of structural systems, whether they are steel, concrete or composite materials, there are several subsystems or components common to all, which can be grouped in: Floor systems, Vertical Load resisting systems, Horizontal Loading systems, Structural Joints and Energy Dissipation systems. For our projects we will study in details the framing system to resist horizontal loadings caused by high wind speeds. [2]

Shear wall buildings normally reach the 30 stories, mostly because of the self weight that they have. However for our project we aim to break the record by designing a building with 75 stories, more than the double that it has been done. However Tube Frames concept for tall buildings was an important step. The exterior and interior columns of the structure are placed so closely together that they not only appear to be solid, but they act as a solid surface as well. The entire building acts as a huge hollow tube with a smaller tube in the middle of it. The lateral loads are shared between the inner and outer tubes.

## 1.2. Problem Statement

The ambition of going high or to reach the sky brings challenge to the design system under high wind speed zones for tall buildings. Building a skyscraper it's not practical, on the other hand developers in crowded cities must make the fullest possible use of limited amounts of available land. Nonetheless, the decision to build a dramatically tall building is usually based not on economics, but on the desire to attract attention and gain prestige.

Finding the best structural system for a 300m tall building under high wind speed, can be challenging in economical terms, the availability of materials, construction management, position of the structural members and different effects from those positions, and the drift effects caused by the wind. This comparison give us a future knowledge in which type of structural system to be used in the high speed wind zones such as KLCC, Kuala Lumpur.

The choose of the software tool its being a problem also, since 3 software's are available which are STAAD Pro 2002 offered by the University, ETABS V9.2 and CYPECAD

2007/2008. All the software's are able to calculate the structures load and design, however all of them are not compatible with Windows Vista (my current Operation System).

## 1.3. Objective

The main objectives of this study are:

1) Compare the structural systems in terms of lateral deflection
2) To determine the effective and robust structural system for 300m tall buildings, under high wind loads, which must satisfactory, comply with the drift criteria.
3) Determine the effective and best member size in order to fulfil design criteria.

## 1.4. Scope of Work

This project will be based on a comparison of 3 structural systems, each one with 300m tall, 75 storeys designed by CYPECAD computer software's. The Wind Loads have been designed using NBR6123 (Brazilian Wind Code). After the design being completed, a structural analysis will be done in order to compare the results in terms of drift analysis, member's sizes and dimensions and effective structural system.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1. Building Design

The design of tall buildings essentially involves a conceptual design, approximate analysis, preliminary design and optimization, to safely carry gravity and lateral loads. The design criteria are strength, serviceability, stability and human comfort. The strength is satisfied by limit stresses, while serviceability is satisfied by drift limits in the range of H/500 to H/1000. Stability is satisfied by sufficient factor of safety against buckling and P-Delta effects.
For our project the following criteria will be taking into consideration:

i. Gravity Loads
ii. Wind Loading and wind effect
iii. Drift Limitation

### 2.1.1 Preliminary Design and Optimization

The structural design of a tall building involves conceptual design, approximate analysis, preliminary design and optimization, followed by detailed and final design. Codes and standards are used effectively to match limiting stresses, displacements and accelerations. Risk analysis with safety and reliability, is often included in arriving at suitable factors of safety in sliding and overturning. Tall narrow buildings develop uplift in the foundations, which should be designed for suitably. The initial selection of a structural system involves architectural, mechanical and electrical requirements. Different floor systems are studied, in combination with 3 to 4 lateral systems, with consequent structural schemes, almost 15 of them, for various combinations between gravity and lateral. Preliminary design and optimization of various schemes follows, in an iterative fashion by satisfying drift and acceleration limits [3].

### 2.1.2 Optimum Structural Systems – Design Issues

The major quantity of interest in arriving at the cost of a structural system is its unit weight, in $kg/m^2$. In other words, the weight is directly associated with the overall efficiency of the system in carrying gravity and lateral loads. The stiffness of the system is associated with weight. An ideal structural system could be the one in which the steel required to carry the gravity loads alone, could carry the wind loads. Optimization could be such that the wind could be carried by keeping stresses within the difference between allowable stresses for gravity plus wind and stresses due to gravity alone, usually a one third increase. However, this is not always possible, as height to width ratios, may not allow this design to be achieved. Some premium for wind is often required. Buildings within about 13 to 14 stories tall, this is often possible. The one third increase allowed in the allowable stresses may be just sufficient to carry wind. Buildings in the 20 to 50 story range, this is not always possible. The structural engineer is required to use innovative schemes like shear wall-frame, shear truss-frame and framed tubes and outrigger braced systems. This premium for wind is often minimized by an optimum design of beams and columns and floor systems to match given stress limits and drift [3].

### 2.1.3 Height to Width Ratios

The efficiency of the structural system is often determined by its height to width ratio. The larger width for any height usually means larger stiffness. This implies larger bay widths, and larger lever arm for flange frames in framed tubes. The optimum height to width ratio should be between 5 and 7. Shear truss-frame buildings, the width of the truss should be less than about 12, relative to its height [3].

### 2.1.4 Span Dimension of Girders

The span length of girders often determines the steel quantity for the floor framing. Smaller spans for exterior frames, will lead to more efficient framed tube systems [3].

### 2.1.5 Member Sizes of Frame

The proportions of members of the frame play a leading role in efficiency, with deeper members being more effective in resisting drift. Deeper members also affect mechanical-architectural cost, and increased floor heights. The design optimization should include these costs. Larger column widths and deeper spandrel may lead to more efficient framed tubes. The orientation of the wider columns should be along the plane of the frame. Column spacing could be arranged in such a way, that all gravity concrete can effectively carry wind, with very little increase in weight for girders. Floor framing should be so arranged that most beams frame directly into columns. Thus, gravity loads could be directly carried without extra girders [3].

### 2.1.6 Floor Framing Design

The floor framing is usually about 20% of the structure weight. It is useful to optimize this subsystem, beforehand. Span to depth ratios, spacing of beams, slab thickness, composite design, and openings for mechanical ductwork, should be carefully considered in floor system design, for efficiency. Span to depth ratios for floor framing are usually good at 20 to 24. This is minimum depth for strength and stiffness. Open web trusses could be used for long spans. Composite action between trusses and slabs should be developed by shear connection. Two way grid systems are often avoided, as fabrication costs are higher. However, in concrete design, they are used if repeating formwork is used. Widest possible spacing of beams and largest spans for slabs should be used. The composite floor systems also have larger stiffness and diaphragm stiffness for the floors. This contributes to overall stability of tall buildings in resisting wind, blast and impact loads. Solid slabs are better than slabs with cellular openings. The diaphragm stiffness is increased [3].

### 2.1.7 Shear Lag Effects

This is an important consideration for framed tube system in extremely tall buildings. This effect should be minimized by using deep spandrels and wide columns and smaller spacing between columns. Transfer beams are used at lower levels to carry less number of openings. The stiffness between column and girder should be balanced. Sometimes, deeper built up I shaped beams are used to increase stiffness. Field welding should be minimized, by using 3 story sub-assemblies of column-girder trees, field bolted at points of inflection. These reduce erection costs. High strength steel is not often beneficial. Fabrication costs are high for these. Reduction in total number of pieces to be assembled will result in cost savings [4].

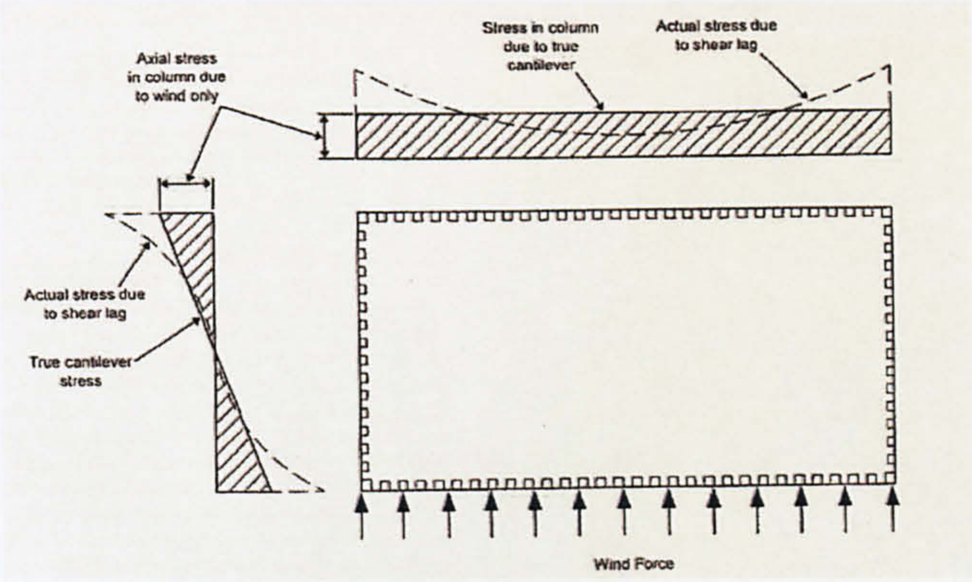



**Figure 2.1:** Shear Lag [5]

## 2.2 Wind Load Structural Systems

In considering the lateral resisting function of tall buildings, three broad types of units may be distinguished, as shown in Figure 2.2:

i. Frames: deform in predominantly shear mode; relative storey deflections depend on the shear applied at the store level.

ii. Wall: deform in an essentially bending mode.

iii. Tubes: if perforated, behave in the same way as walls. However, openings which are normally present in units of this type produce a behaviour intermediate between that of a frame and a wall.

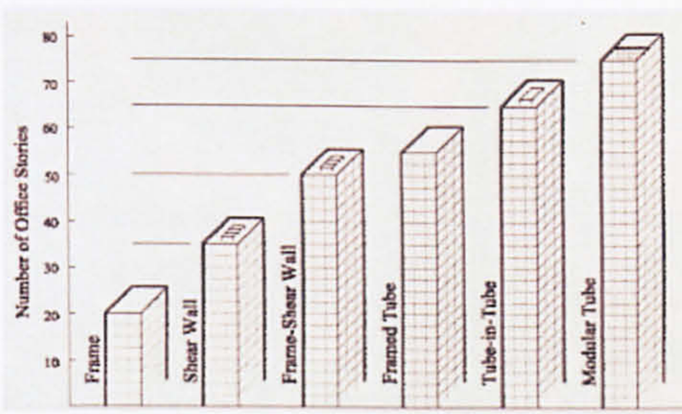



**Figure 2.2:** Structural Systems [4]

### 2.2.1 Exterior Structures

The nature of building perimeters has more structural significance in tall buildings than in any other building type due to their very tallness, which means greater vulnerability to lateral forces, especially wind loads. Thus, it is quite desirable to concentrate as much lateral load-resisting system components as possible on the perimeter of tall buildings to increase their structural depth, and, in turn, their resistance to lateral loads.

One of the most typical exterior structures is the tube, which can be defined as a three-dimensional structural system utilizing the entire building perimeter to resist lateral loads. The earliest application of the tubular notion is attributed to Fazlur Khan, who thought of this concept in 1961 and designed the 43-story DeWitt-Chestnut Apartment Building in Chicago, completed in 1965, the first known building designed as a framed tube. A few other worlds' tallest buildings using this concept is the World Trade Center in New York already destroyed.

### 2.2.2 Shear Walls

Shear wall have been the most common structural system used in the past for stabilizing building structures against horizontal forces caused by wind or earthquakes. With the advance of reinforced concrete, shear walls systems have became widely used to stabilise efficiently even the tallest building structures.

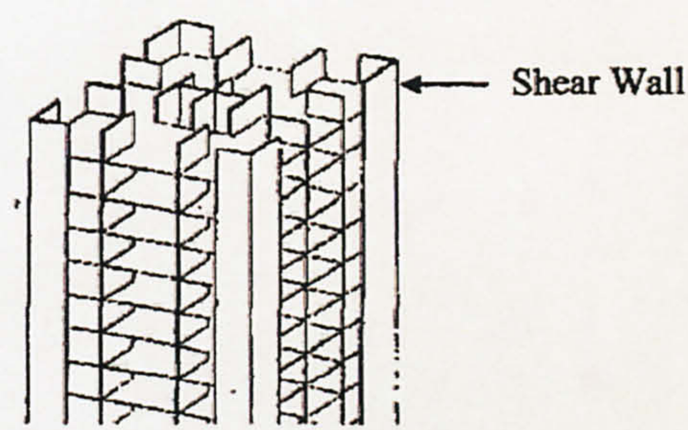



**Figure 2.3:** Shear Wall Structure [13]

#### 2.2.2.1 Advantages Of Shear Walls

i. They are very rigid in their own plane and hence are effective in limiting deflections.

ii. They act as fire compartment walls. However, for low and medium rise buildings, the construction of shear walls takes more time and is less precise in dimensions than steelwork. Generally, reinforced concrete walls possess sufficient strength and stiffness to resist the lateral loading. Shear walls have lesser ductility and may not meet the energy required under severe earthquake.

A common shear wall system used for tall buildings groups shear walls around service cores, elevator shafts, and stairwells to form a stiff-box type of structure. The walls are designed to cantilever from the foundation level. To design shear walls arranged around service cores, the bending, shear and wrapping stresses due to wind or earthquake loads are combined with stresses due to gravity loads. Reinforcement is proportionate as follows:

i. Minimum shrinkage restraint reinforcement where the wall stresses are low, which can be for a substantial portion of the shear wall.
ii. Tensile reinforcement for areas where tension stresses occur in walls when wind uplift stresses exceed gravity stresses.
iii. Compressive reinforcement with confinement ties where high compressive forces require that walls be designed as columns. Individual shear walls, say at the edge of a tall building, are designed either as blade walls or as columns resisting shear and bending as required [6]

#### 2.2.2.2 Construction Advantages of Reinforced Concrete Shear Walls

i. Central-services core shear walls can be efficiently constructed using slip-form or jump-form techniques.
ii. High concrete has enabled wall thickness to be minimized and hence rentable floor space.
iii. Technology exists to pump and place high-strength concrete at high elevations.
iv. Fire rating for service and passenger elevator shafts is achieved by simple placing concrete at a determinate thickness.
v. The need for complex bolted or side-welded steel connection is avoided.

Although these advantages make concrete shear wall systems a competitive construction method, the following must be considered:

i. Shear walls formed around the elevator and services risers require a concentration of openings at ground level where stresses are critical.
ii. Torsional and flexural rigidity is affected significantly by the number and size of openings
iii. Shear wall vertical impact of the building will continue throughout the life of the building. Their impact on the building must be analysed at the design stage.
iv. The additional weight of the concrete structure related to steel will induce a cost penalty for the foundations.
v. An increase in mass will cause a decrease in natural frequency and hence will most likely produce an adverse effect of the acceleration response depending on the frequency range of the building. But shear wall systems are usually stiff and cause a compensating increase in natural frequency [6]

#### 2.2.2.3 Coupled Shear Wall

Multiple shear walls throughout a tall building may be coupled to provide additional frame action and hence increase overall building stiffness. Coupling can be realized by relatively shallow header or link beams within the ceiling cavity at each level or by means of one or two story high shear coupling walls. By adding a coupling shear wall at a single level, reverse curvature is induced in the core above the coupling shear wall significantly reducing lateral drift by increasing the overall building stiffness. As the increase in mass is minimal, there will be an increase in the building natural frequency. This can be a desired effect, in particular with respect to achieving an acceptable wind-induced acceleration response to ensure human comfort. Consist of two or more shear walls in the same plane, or almost the same plane, connected at the floor levels by beam or stiff slabs.

The effect of the shear-resistant connecting members is to cause the sets of wall to behave in their partly as a composite cantilever, bending about the common centroidal axis of the walls.

Suited for residential construction where lateral-load resistant cross walls, which separate the apartments, consist of in-plane coupled pairs, or trios, of shear walls between which there are corridor or window openings. Besides using concrete construction, it occasionally been constructed of heavy steel plate, in the style of massive vertical plate or box girders, as part of steel frame structure [4].

A wall-frame structure is a structure whose resistance to horizontal loading is provided by a combination of shear wall and rigid frame. The shear wall or braced bents are often parts of the elevator and service cores, while the frames are arranged in plan, in conjunction with walls, to support the floor system

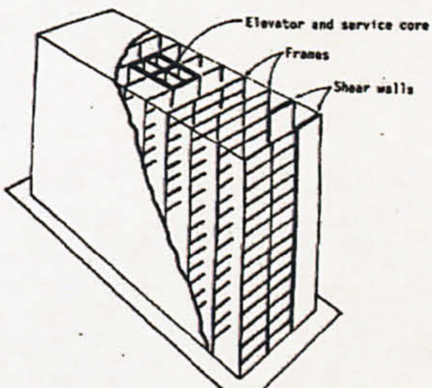



**Figure 2.4:** Wall Frame Structure [13]

When a wall-frame structure is loaded laterally, the different free deflected forms of the wall and the frames cause them to interact horizontally through the floor slabs. Consequently, the individual distribution of lateral loading on the wall and the frame may be very different from the distribution of the external loading. The horizontal interaction can be effective in contributing to lateral stiffness. This, cause wall-frames structures up to fifty stories or more to be more economical.

Wall-frame structures consist of walls and frames in the same plane (Figure 2.5a). In this structure, the wall and frame is a planar bent interact horizontally through axial forces in the connecting beams and slabs. Other than that, wall frames structures may also consist of walls and frames in parallel bents (Figure 2.5b). The horizontal resistance is then provided by the walls and frames in parallel bents. They are constrained to deflect identically by the in plane rigidity of the floor slabs and therefore, interact horizontally through shearing actions in the slab.

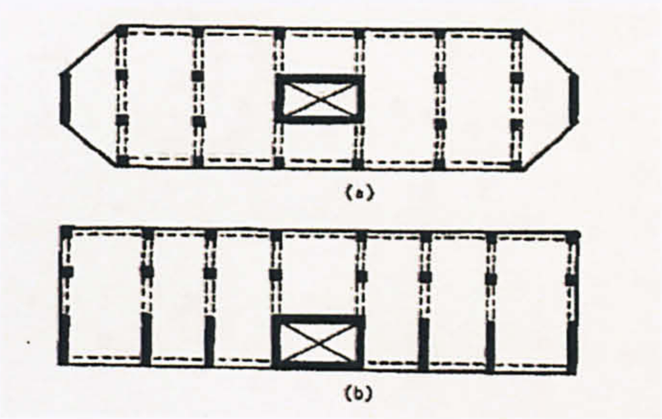



**Figure 2.5:** Wall and Frame in Same Bents [13]

The advantages of a wall-frame structure compared with a rigid-frame and shear wall structures depend on the amount of horizontal interaction. This governed by the relative stiffness of the walls and frames, and height of the structure. The taller the building and, typically in proportioned structures, the stiffer the frames and greater the interaction. It used to be common practise in the design of high-rise structures to assume that the shear walls or cores resisted all the lateral loading, and to design the frames for gravity loading only. This assumption would have incurred little error for buildings of less than 20 stories with flexible frames. That is when the wall is much more rigid than the rest of the structure.

#### 2.2.2.4 Behaviour of Wall Frame Structure

From the Figure 2.6 we can see that the frame basically deflects in a so called shear mode while the shear wall predominantly responds by bending as a cantilever. Compatibility of horizontal deflection produces interaction between the two. The linear sway at the moment frame, when combined with the parabolic sway of the shear wall results in an enhanced stiffness because the wall is restrained by the frame at the upper levels while at the lower levels the shear wall is restrained by the frame. However is not always easy to differentiate between the two nodes because a frame consisting of closely spaced columns and deep beams tends to behave more like a shear wall responding pre-dominantly in bending mode. And similarly, a shear wall responding by large openings may tend to act more like a frame by deflecting in a shear mode. The combined structural action, therefore, depends on the relative rigidity of the two, and their modes of deformation. This interaction is only valid only if:

i. The shear wall and frame have constant stiffness throughout the height;
ii. If stiffness's vary, the relative stiffness of the wall and frame remains unchanged throughout the height

This type of system has wide applications for buildings up to about 40 to 70 stories in height [4].

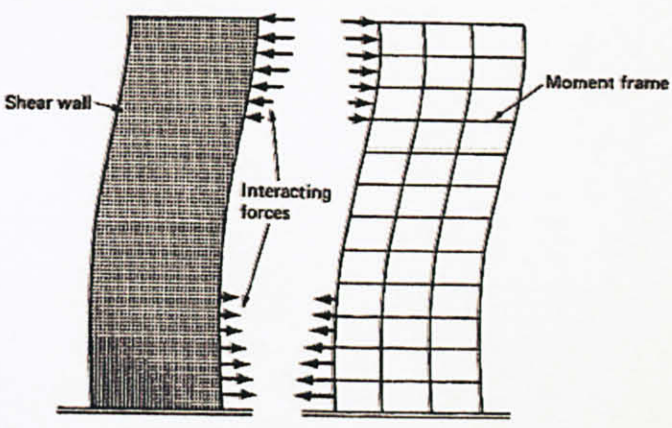


**Figure 2.6:** Shear Wall Behaviour [5]

### 2.2.3 Framed Tube System

In its simplest terms, the tube system can be defined as a fully three-dimensional system that utilizes the entire building perimeter to resist lateral loads. At present four of the world's tallest buildings are tubular systems. They are the 110-story Sear Tower, the 100-story John Hancock Building, and the 83-story Standard Oil Building all in Chicago, and the 110-story World Trade Center Towers in New York. The earliest application of the tubular concept is credited to the late Dr. Fazlur Khan which first introduced the system in a 43-storey apartment building in Chicago [4].

The introduction of the tubular system for resisting lateral loads has brought about a revolution in the design of high-rise buildings. All recent high-rise buildings exceeding 50 to 60 storey employs tubular concept in one form or another. In essence the system strives to create a three-dimensional wall-like structure around the building exterior. In a framed tube this is achieved by arranging closely spaced columns and deep spandrels around the entire perimeter of the building. Because the entire lateral load is resisted by the perimeter frame, the interior floor plan is kept relatively free of core bracing and large columns, thus increasing the net leasable area of the building. The structural optimization reduces to examining different columns spacing and member proportions. In practise the frame tubular behaviour is achieved by placing columns at 10ft (3.05m) to as much as 20ft (6.1m) apart, with spandrel depth varying from 3 to 5ft (0.9 to 1.52m) [4, 5, 7]

#### 2.2.3.1 Framed Tube Behaviour

To understand frame tube behaviour, consider a square shaped building consisting of closely spaced exterior columns and deep spandrel beams. Assuming that the interior columns are designed for gravity loading only, their contribution to lateral load resistance is negligible. The floor system, as in other types of lateral bracing systems is considered a rigid diaphragm and is assumed to distribute the wind load at various elements according to their stiffness. Its contribution to lateral resistance in terms of it's out-plane action is considered negligible. The system resisting the lateral load thus comprises of 4 orthogonal rigidly jointed panels forming a tube in plan as shown in Figure 2.7.

The frame panels are formed by closely spaced perimeter columns that are connected by deep spandrel beams at each floor level. In such structures, the "strong" bending direction of the column is aligned along the face of the building in contrast to the typical rigid frame bent structure where it is aligned perpendicular to the face. The basic requirement has been to place as much of the lateral load-carrying material at the extreme edges of the building to maximize the inertia of the building cross section. Consequently, in many structures of this form, the external tube is designed to resist the entire lateral loading. The frames parallel to the lateral load act as a web of the perforated tube, while the frames normal to the loads act as a flange. Vertical gravity load is resisted partly by the exterior frames and partly by some interior columns or an interior core. When subjected to bending under action of lateral forces, the primary mode of action is that of a conventional vertical cantilever tube, in which the columns on opposite sides of the neutral axis are subjected to tensile and compressive forces.

In addition, the frames parallel to the direction of the lateral load are subjected to the usual in plane bending, and the shearing or racking action associated with an independent rigid frame. The discrete columns and spandrels may be considered in conceptual sense, equivalent to a continuous three-dimensional wall. The model becomes a hollow tube cantilevering from the ground with a basic stress distribution show in Figure 2.7.

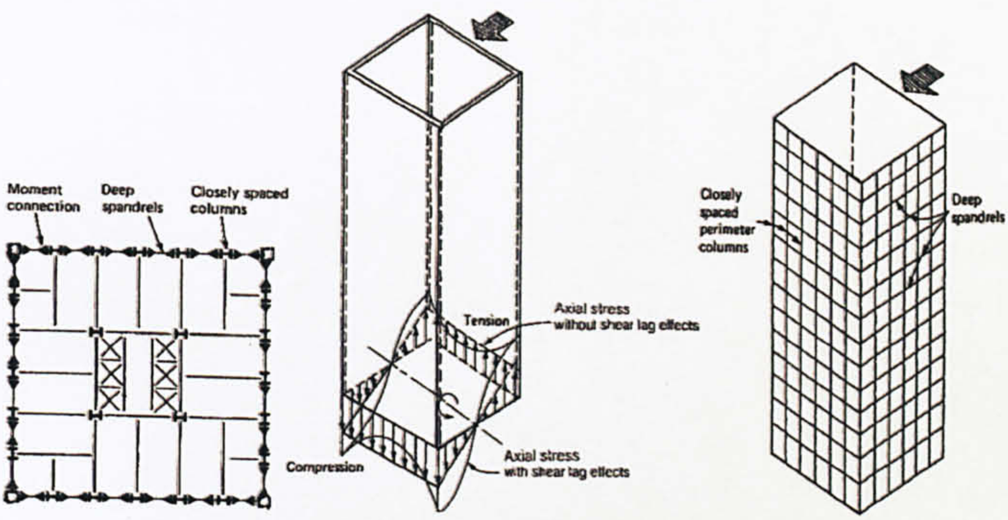



**Figure 2.7:** Axial stress distribution in a square tube [4]

Although the structure has a tube-like form, its behaviour is much more complex than that of a solid tube; unlike a solid tube it is subjected to shear lag effects. The influence of shear lag is to increase the axial stresses in the corner columns and reduce those in the inner columns of both the flange and web panels as shown by dotted lines, in Figure 2.7. Ignoring the shear lag consequences for now, the analogy of the hollow tube can be used to visualise the axial stress distribution in buildings with other plan forms such as rectangular, circular and triangular. This philosophy of creating a fully three-dimensional structural system utilizing the entire building foot-print to resist lateral loads has allowed for considerable freedom in manipulating building plans. The rigorous organization of orthogonal bay spacing required with the previous types bracing is no longer necessary. The only requirements are for the structure to be continuous around the exterior to invoke a three-dimensional response, and be of a closed-cell form, to resist Torsional loads. Depending upon the height and dimensions of the building, the exterior columns spacing is usually of the order of 10 to 15ft (3 to 4.6m), although a spacing as close as 3.8ft (1.0m) has been used for the 110-storey World Trade Center Twin Towers. The efficiency of the system is directly related to building height-to-width ratio, plan dimensions, spacing, and size of columns and spandrels [4].

#### 2.2.3.2 Tube-In-Tube

The stiffness of a framed tube can also be enhanced by using the core to resist part of the lateral load resulting in a tube-in-tube system. The floor diaphragm connecting the core and the outer tube transfer the lateral loads to both systems. The core itself could be made up of a solid tube, a braced tube, or a framed tube. Such a system is called a tube-in-tube, an example of which is the 52-story One Shell Plaza of 1971 in Houston, Texas. It is also possible to introduce more than one tube inside the perimeter tube.

The inner tube in a tube-in-tube structure can act as a second line of defence against a malevolent attack with airplanes or missiles. For example, a solid concrete core in the World Trade Center in New York could probably have saved many lives of those who were trapped in fire above the levels of airplane impact [5].

## 2.3 Drift Limitations

Calculation of drift limits it's the major tasks in the analysis of tall buildings frames. The deflection depends on factors such as height-to-width ratio and the relative rigidity of the column to girder connection. A simple method is by assuming a tall building as an inverted cantilever beam where the each axial stress in each column is proportional to its distance from the centroidal axis of the frame.

The maximum drift index assumed for this project is equal to ***H/500***, which is: ***300/500=0.60m or 600mm.***

## 2.4 Wind Design

### 2.4.1 General

The wind loading is the most important factor that determines the design of tall buildings over 10 storeys, where storey height approximately lies between 2.7 – 3.0 m. Buildings of up to 10 storeys, designed for gravity loading can accommodate wind loading without any additional steel for lateral system. Usually, buildings taller than 10 storeys would generally require additional steel for lateral system. This is due to the fact that wind loading on a tall building acts over a very large building surface, with greater intensity at the greater heights and with a larger moment arm about the base. So, the additional steel required for wind resistance increases non-linearly with height. The lateral stiffness of the building is a more important consideration than its strength for multi-storeyed structures. Wind has become a major load for the designer of multi-storeyed buildings. Prediction of wind loading in precise scientific terms may not be possible, as it is influenced by many factors such as the form of terrain, the shape, slenderness, and the solidarity ratio of building and the arrangement of adjacent buildings. The appropriate design wind loads are estimated based on two approaches.

Static approach is one, which assumes the building to be a fixed rigid body in the wind. This method is suitable for buildings of normal height, slenderness, or susceptible to vibration in the wind. The other approach is the dynamic approach. This is adopted for exceptionally tall, slender, or vibration prone buildings. Sometimes wind sensitive tall buildings will have to be designed for interference effects caused by the environment in which the building stands. The loading due to these interference effects is best ascertained using wind tunnel modelled structures in the laboratory.

### 2.4.2 Design Wind Speeds

The basic design wind load is the velocity pressure of a wind lasting for few seconds that will be exceeded on the average once in 50 years. Every station has pressure tube anemometers that record such gust speeds. The only wind records covering many stations and many years are of the kilometres of wind passing the spinning cup anemometer each hour. The annual maximum of these hourly mean wind speed have been analysed to yield that will be exceeded on the average once in 50 years. Peak gust at the few stations where they are recorder have been compared with corresponding hourly speeds, and the resulting relationship has been used to estimate peak gust at other stations.

Average wind speeds at low levels in cities are much less than those in open country. The gustiness of city winds is greater, however, and peak gust in a city may not be much less than peak gusts at a nearby airport. It is therefore somewhat conservative but reasonable to use measured or estimated peak gust speeds at an airport as the design wind speed for the building up to 10 metres high in a city or town.

Gust speeds at higher levels are stronger than those near the surface. Because gustiness decreases with height, however, increase in the speed of peak gust with height will be less than the increase in mean wind speeds. For flat open country the exponent for gust speeds is probably about 1/10. For average conditions the more conservative exponent of 1/7 is commonly used.

### 2.4.3 Dynamic Effect

Every structure has a natural frequency of vibration, and should dynamic loading occur at or near it, structural damage out of all proportion to the size of the load may result. Certain periodic gust within the gustiness in the wind may find resonance with the natural vibration frequency of a building, and although the total force cause by that particular gust frequency will be much less than the static design load for the building, dangerous oscillations may be set up.

The wind pressure originates from two components: mean velocity and gust velocity.
This mean velocity are averaged over long periods of time, the resulting wind pressures are also average pressures and exert a steady deflection on the building. The dynamic gust velocities produce correspondingly dynamic wind pressures that create additional displacement to the deflection of the building. The random forces created by gust action induce building oscillation generally parallel to the wind direction. For this study, only in static analysis by using mean velocity of wind pressure will be considered.

Response of a building: Under the action of a natural wind, a tall building will be continually buffeted by gust and other aerodynamic forces. Although the structure will tend to deflect toward a mean position, it will occur primarily at the fundamental period of vibration of the building. Thus, the response of the structure to the turbulent wind environment is predominantly in the first mode of vibration. The first of fundamental period vibration of a multidegree-of-freedom system is the time it takes to complete one full cycle when vibrating in its natural mode having the lowest frequency. The fundamental mode of vibration of a vertical structure generally involves displacements of all the masses toward the same side of the original position, while the higher modes involve reversals in displacement masses.

Aerodynamic instability: If that portion of the wind energy that is absorbed by the structure is larger than that which is dissipated by the structural damping, then the amplitude of oscillation will continue to increase and will finally lead to destruction.

### 2.4.4 Variables Affecting Pressures Distribution

*Building shape*: Pressures on certain parts of a structure are rather sensitive to changes in the shape of the building. The suction on the windward roof slope varies with the sloop of the roof, the height to width, and the ratio width to length of the building. Suction on the leeward wall, on the other hand, are not greatly affected by such variables.

*Openings*: the size of openings such as windows and doors determine the internal pressure that must be considered in the calculation of the net force on walls and roofs.

*Wind Direction*: The orientation of a building to the wind has a clear effect on pressure distribution, particularly on suction, which occurs over a small area near the leading edges of roofs.

*Increase of wind speed with height*: Wind speeds and velocity pressures increase with height above the ground. A height factor is applied to the basic pressure (based on a height of 10m) in the design of building.

*Shielding*: other building, trees and similar large objects in the immediate surrounding area have a bearing pressure distribution. The shielding provided is usually difficult to estimate, and model tests provide the most convenient means of determining design values.

*Critical Angle, Windward Slope*: For every sloped roof there is a certain slope angle at which the suction coefficient over the windward slope reaches a numerical maximum. For high buildings with height to width ratios ranging up to 2:1 the critical angel may be as high as 25 or 30 degrees.

*Leeward Slope*: The effect of slope and building dimension ratios are much less pronounced on suction on the leeward slope and for general purposes could probably be disregarded. Average values range from -0.5 to -0.8 for most building shapes and slopes.

*Walls*: For tall, slender structures designed of the walls and frames, with regard to overturning moment, are likely to be critical. The trend toward high-rise buildings and curtain wall construction may lead to greater problems in limiting sway. Average coefficients for leeward and side walls are only -0.5 to -0.7 and high suctions occur just around the corners from the windward edges, and where the stagnation pressures are high.

### 2.4.5 Estimating Wind Pressures

This method describes a static approach in that it assumes the building to be a fixed rigid body in the wind. Static method is appropriate for tall buildings of unexceptional height, slenderness or susceptibility. The subsequently is dynamic method that for exceptionally tall, slender, or vibration-prone buildings. Some of the considerations which enter into the choice of a design wind pressure are:

i. The anticipated lifetime of the structure and its relation to the return period of maximum wind velocity;
ii. The duration of gust;
iii. The dimension of gust
iv. Variation of wind speed with height;
v. Angle of incidence of the wind;
vi. Influence of the ground effect;
vii. Influence of architectural features;
viii. Influence of internal pressures;
ix. Lateral resistance of structure.

#### 2.4.5.1 NBR 6123 (Brazil Wind Code)

This method takes into account for the effects of gusting and for local differences in exposure between the open countryside and the city centre, as well as the allowing for vital facilities, whose safety must be endured for use after an extreme windstorm. This is the design code integrated in the design software, where the design wind pressure is obtained from the formula [9].

$$\boxed{P = q \cdot C_a}$$

$$\boxed{q = 0.613\ V_k^{\ 2}}$$

$$\boxed{V_k = S_1.\ S_2.\ S_3.\ V_0}$$

In which, $\boldsymbol{P}$ is the wind pressure, $\boldsymbol{q}$ is the Dynamic pressure, $\boldsymbol{C_a}$ is the Drag coefficient, $\boldsymbol{V_k}$ is the characteristic velocity of the wind. Topographic factor ($\boldsymbol{S_1}$) considers the variation of terrain superficies, where for flat terrain is considered as 1. $\boldsymbol{V_0}$ is the Basic wind speed for a 3s storm exceeded once in 50 years at 10m above the ground, and $\boldsymbol{C_a}$ as the Drag Coefficient.

#### 2.4.5.1.1 Roughness Factor

It is classified into 5 categories:

*Category 1*: smooth superficies with extensive dimension, more than 5 Km. Example: lakes & rivers, sea shore, and wetlands.

*Category II*: open land with few obstacles, such as trees, and small buildings. The obstacles are less than 1.0m of height. Example: coastal areas, wetlands with vegetation, aviation fields, farm houses.

*Category III*: plain fields or wavy with obstacles such as trees, low rise buildings, walls, hedges, etc. The maximum height for the obstacles is about 3.0 m. Example: suburbs with low rise houses, and buildings.

*Category IV*: land covered with many obstacles in jungles, industrial zones, or urbanized. Obstacles height is approximately 10 m. Examples: zone covered with parks, with many trees, small cities and big cities suburbs, industrialized areas.

*Category V*: land covered with many high obstacles. Obstacles a higher than 25m.Example: city centres, jungles with high trees, well developed industrial complexes.

#### 2.4.5.1.2 Building Dimension

*Class A:* Buildings that the horizontal and vertical dimensions don't exceed 20m.
*Class B:* Buildings that the horizontal and vertical dimensions are between 20m and 50m.
*Class C:* Buildings that the horizontal and vertical dimensions exceed 50m.

#### 2.4.5.1.3 Statistic Factor

**Table 2.1:** Statistic Factor

| Group | description | S3 |
|---|---|---|
| 1 | Buildings that the ruins may affect the safety during rescue. Examples hospitals, fireman's, etc | 1.10 |
| 2 | Buildings such as hotels, residences, industries, commerce, with a high degree of occupation | 1.00 |
| 3 | industries with small factor of occupancy | 0.95 |
| 4 | fences, claddings | 0.88 |
| 5 | temporary constructions from group 1 to 3 | 0.83 |

#### 2.4.5.1.4 Design Considerations

There is still a need to understanding the nature of wind and its interaction with a tall building, with particular reference to allowable deflections and comfort of occupants. In designing of tall buildings to withstand wind forces, the following are the important factors that must be considered:

i. Strength and stability requirements of structural elements
ii. Fatigue in structural members and connections caused by fluctuating wind loads
iii. Excessive lateral deflections that may cause cracking and permanent deflections
iv. Frequency and amplitude of sway that cause discomfort to occupants
v. Possible buffering that may increase the magnitudes of wind velocities on neighbouring buildings
vi. Effects pedestrians
vii. Annoying acoustical disturbances [2].

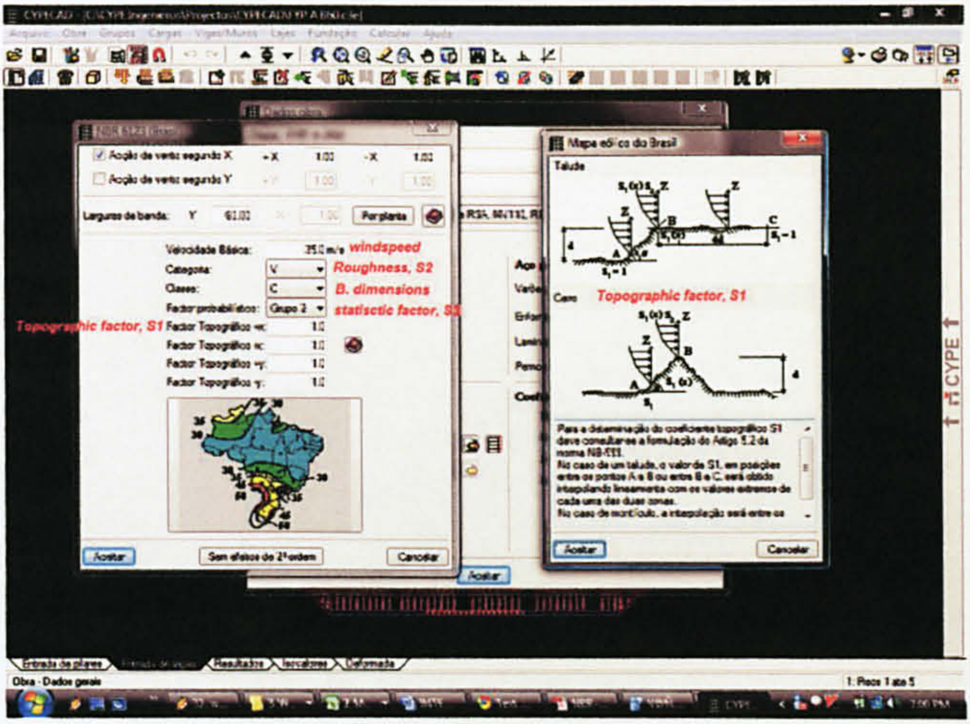



**Figure 2.8:** Data Input in CYPECAD

# CHAPTER 3

# METHODOLOGY

***3.1. Background Research***: design criteria, wind loading & effects, structural system

***3.2. Wind Loading calculation and Pressure Calculation***

***3.3. Building Design using the Software CYPECAD 2007***: design of columns, design of beams, design of slabs, design of shear walls

***3.4. Structural analysis*** of the structure in terms of deflections, drift limitations, structural dimensions.

***3.5. Optimal design***, which fulfils all the design criteria for this project, and conclusion of FYP.

### 3.6 Tools and Equipment

#### 3.6.1 CYPECAD 2007

CYPECAD was brought about to carry out the analysis and design of reinforced concrete and steel structures, subject to horizontal and vertical forces, for houses, buildings and civil work projects. Its use guarantees maximum analysis liability and the one of the best drawing design, including the following elements:

i. Floor slabs
ii. Beams
iii. Supports
iv. Stairs
v. Foundations
vi. General data
vii. Data entry (Structure geometry)
viii. Integrated 3D structures (Connection between CYPECAD and Metal 3D)
ix. Analysis
x. Results
xi. Drawings
xii. Reports [12]

### 3.7 Project Description & Activities

There are three types of structural systems to be modelled in this project. Figure 4.8, 4.9, 4.10 shows the typical floor layout plan of these buildings that will be used for modelling. The structures will be 75 storeys tall; each floor with 4m, which would add up to a total height of 300m. The main activity for this project is the basic design concepts and structural analysis. Following are the basic steps of designing using the CYPECAD2007 software:

### i. *Design of frame structure of the building (spans, height, loads)*

The frame consists of a 60m x 60m plan view, with columns spans of 12m each for internal columns, and 3m for external columns in the tube frames. The design Live Load was considered to be 3.6kN/m$^2$.

### ii. *Design of columns (size, stiffness)*

Figure 3.1 shows the software layout for the input of columns dimensions according to the storey floors. We also input the end condition coefficients for the columns, making them to carry moments.

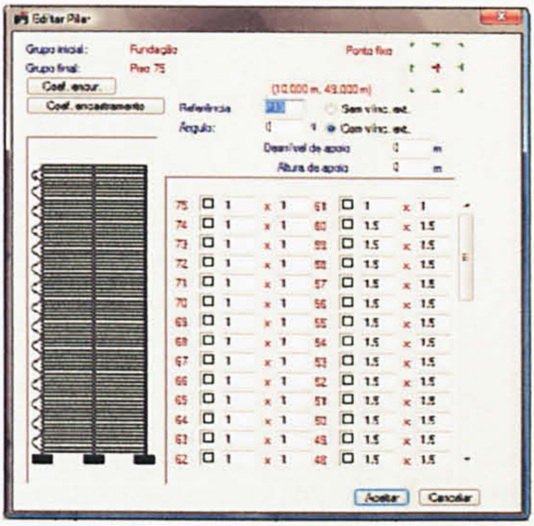


**Figure 3.1:** Columns Design Layout

### iii. *Design of shear walls (position, size)*

Shear Walls were designed with 12m long filling two of the spans on each facade of the shear wall building. Thicknesses of the shear wall used for the structure are 30cm, 40cm, 50cm and 60cm which may be analysed in terms of the building deflection.

### iv. *Design of beams (size, types)*

Beams were designed in order to carry Moments. For this, deep beams with dimensions of 0.5m x 1.5m for internal frame, and 0.5m x 0.6m for external structures in the Tube Frame and Tube in Tube were modelled. Figure 3.2 shows the layout of beam design using CYPECAD; the type and dimension of the beam may be chosen and inputted here. The two red lines in the cross section of the beam, defines the position of the slab, which may vary according to the slab thickness.

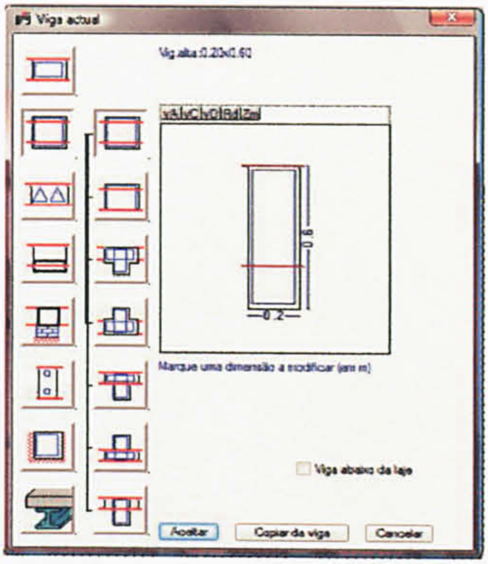



**Figure 3.2:** Beam Design Layout

### *v. Design of slabs (dimensions, types)*

Slab was designed using pre-casted beams or joist with hollow blocks. This type of slab offers a rapid analysis and structural calculation comparing to the solid slabs. A thickness of 25mm was used for the modelling in order to support the long spans between the beams. Figure 3.3 shows the dimensions and assumptions for the hollow blocks as well the pre-casted beams or joist.

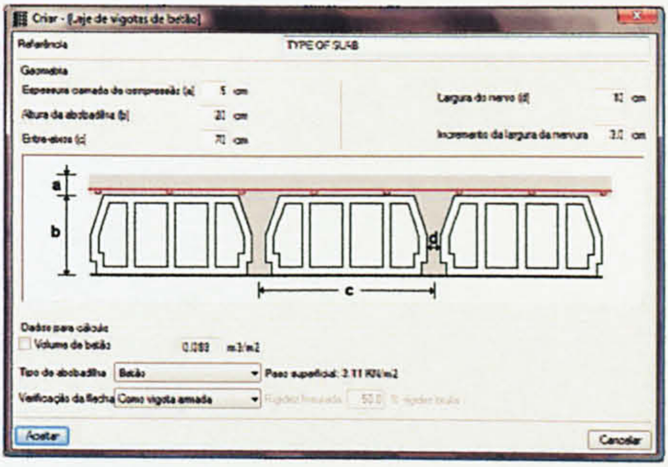



**Figure 3.3:** Slab Design Layout

### *vi. Structure calculation*

The structures would be calculated using spatial analysis of 3D with matrix methods of rigidity considering all the elements which define the structure such as: columns, beams, walls, slabs.

### *vii. Structural analysis (analysis of the structure according to deflection)*

Once the structures are calculated, a check of the members size, reinforcements need to be done in order to members be correctly designed. Figure 3.4 shows the columns analysis and steel distribution, and the beams reinforcement design.

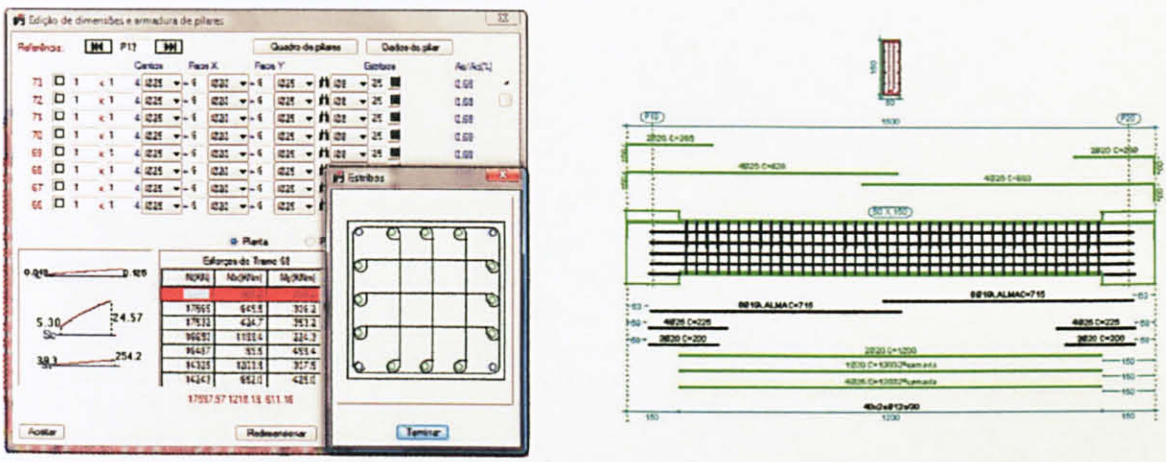


**Figure 3.4:** Reinforcement Analysis for Columns, and Beams

### *viii. Optimal design*

At this stage, all the analysis has been done. The comparison between the buildings in order to compare them in terms of horizontal deflection, volume of concrete, amount of steel, etc will determine the optimal design for the project.

## 3.8 Design Information and Assumptions

### 3.8.1 Design Codes

Building Code and Standards are documents which serve as compendiums for technical information and as sources for extracting minimum requirements of accepted design and construction practises [2]. Next are the basic Building Codes used to design and compare results in our project:

i. NBR 6123: 1998 - Brazil Code for Wind
ii. REBAP & RSA - Portugal Code for concrete

### 3.8.2 Building Design

- Frame Material: Concrete
- Foundation: N/A
- Earthquake Load: N/A
- Materials: Concrete Grade: C50
  Steel Grade: 500MPa
- Slab: Live Load: 3.6kN/$m^2$
  Thickness: 25mm (pre-casted beams, with hollow block)
- Maximum Lateral Deflection: H/500 = 600mm

#### 3.8.2.1 Shear Wall Building

- Type of Structure: Shear wall Frame Structure (refer to Figure 4.6)
- Shear Wall Thickness: 30cm, 40cm, 50cm & 60cm

- Columns:

    Spacing: 12m

    Level 1 to level 20: 2.5m x 2.5m

    Level 21 to level 40: 2m x 2m

    Level 41 to level 60: 1.5m x 1.5m

    Level 61 to 75: 1m x 1m

- Beam Spans: 12m
- Beam dimensions: 0.5m x 1.5m

#### 3.8.2.2 Frame Tube Building

- Type of Structure: Frame Tube Structure (refer to Figure 4.7)
- Columns:

    Interior Colum Spacing: 12m

    Level 1 to level 20: 2.5m x 2.5m

    Level 21 to level 40: 2m x 2m

    Level 41 to level 60: 1.5m x 1.5m

    Level 61 to 75: 1m x 1m

    Perimeter Columns Spacing: 3m

    0.5m x 1.0m, 0.6m x 1.0m, 0.7m x 1.0m, 0.8m x 1.0m

- Beam Spans: 12m, 3m
- Beam dimensions: 0.5m x 1.5m, 0.5m x 0.6m

#### 3.8.2.3 Tube in Tube Building

- Type of Structure: Tube in Tube Structure (refer to Figure 4.8)
- Columns:

    Interior Colum Spacing: 12m

Level 1 to level 20: 2.5m x 2.5m

Level 21 to level 40: 2m x 2m

Level 41 to level 60: 1.5m x 1.5m

Level 61 to 75: 1m x 1m

Perimeter Columns Spacing: 3m

0.5m x 1.0m, 0.6m x 1.0m, 0.7m x 1.0m, 0.8m x 1.0m

- Beam Spans: 12m, 3m
- Beam dimensions: 0.5m x 1.5m, 0.5m x 0.6m

# CHAPTER 4

# RESULTS & DISCUSSION

## 4.1 NBR 6123

For the following design, using CYPECAD, we input the following criteria which can also be seen in the Figure 2.9:

Wind speed: 35m/s

Category: V

Class: C

Statistic Factor: 2

Topographic Factor = 1

From the data input in the software, the following results have been generated. Notice that the wind load increase as the height also increases. In the appendices we can find the Table A1 showing all the values for the wind load output from the analytical software.

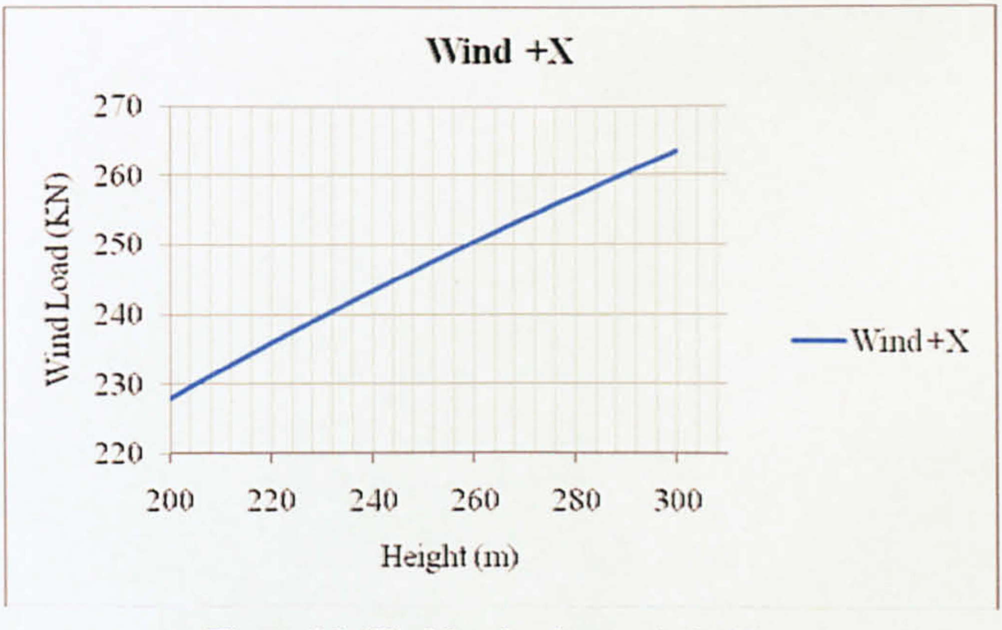



**Figure 4.1:** Wind Load acting on the building

## 4.2 Effects of member size dimension on drift analysis

From the Figures 4.2 to 4.4, we can see that the thickness of shear wall, the size of columns in the Frame, and Tube in Tube Structural System has an effect in the horizontal drift. As we increase the dimensions of the members, the horizontal deflections of the 3 buildings reduce. This may be caused by the bigger section of the members which can support greater amount of shear loads and moments. These members' dimensions also contribute to the rigidity of the building by having a great stiffness.

Engineers manage to save costs by minimising the member dimensions, so from the Figures 4.2 to 4.4 we can analyse and reach a conclusion for the most optimum member dimension for the design criteria. However for the drift analysis, the bigger the member size, the smaller the deflection.

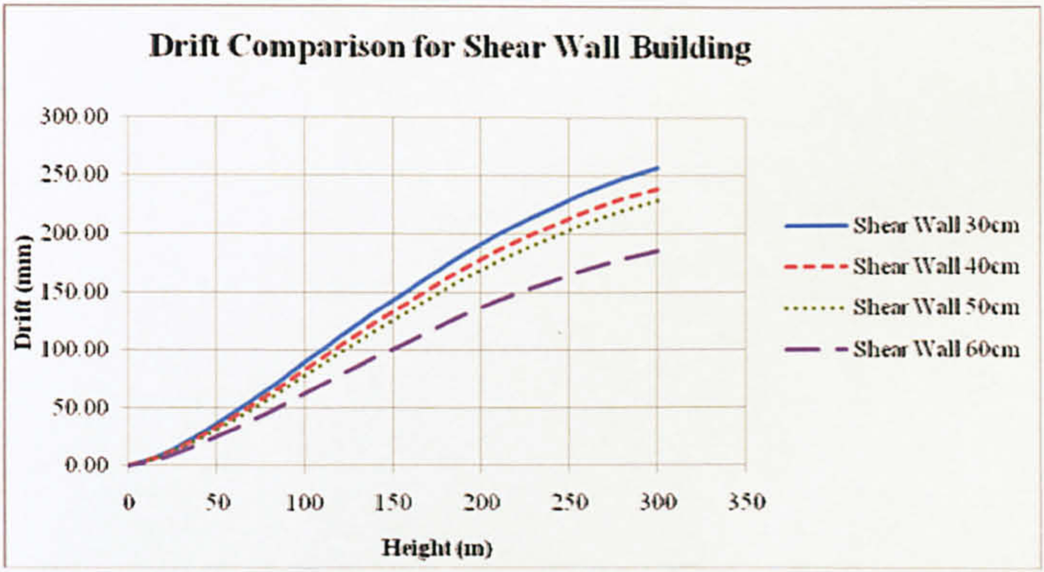



**Figure 4.2:** Drift Comparison for Shear Walls Buildings

From the Figure 4.2, we can observe that as we increase the thickness of the shear wall the drift reduces, and that there is a little difference between the drift of the shear wall with 40cm thickness comparing to the 50cm. The internal columns carry the gravitational load of the slabs and beams. These columns are affected also by horizontal loads from the wind and deflect according to the height; Table A2 to A13 in the appendices shows the deflection results for the columns.

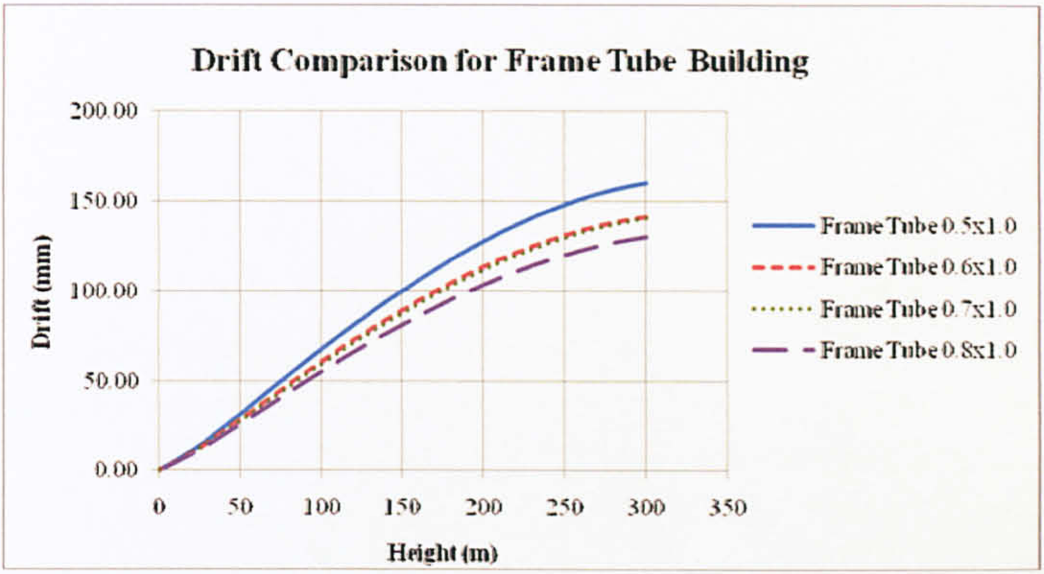



**Figure 4.3:** Drift Comparison for Frame Tube Buildings

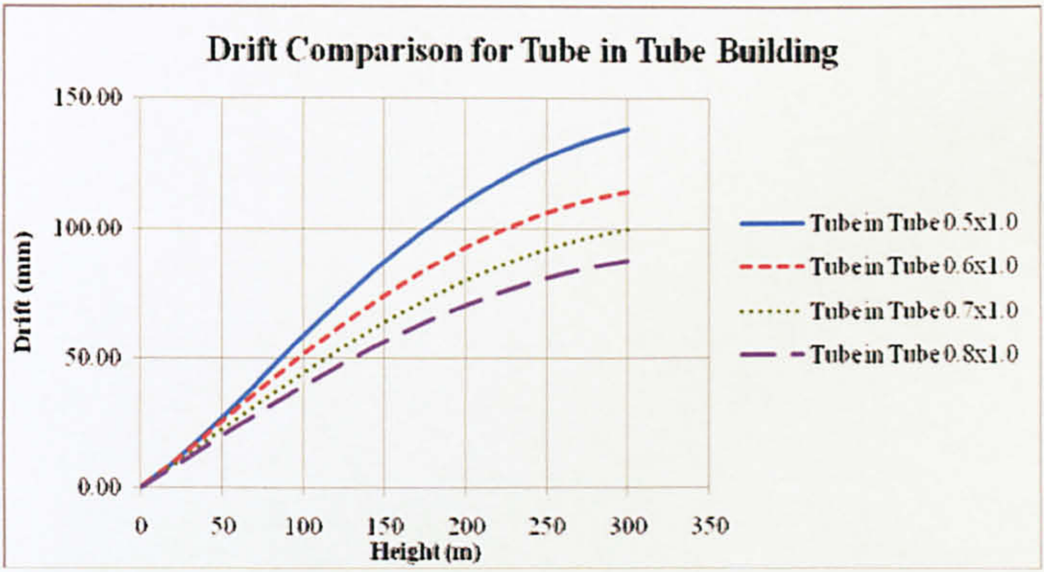



**Figure 4.4:** Drift Comparison for Tube in Tube Buildings

Figure 4.3 and 4.4 shows the drift according to the height of the Frame Tube Building and Tube in Tube. In these buildings the columns dimensions were changed and analysed from the cross sections of 0.5m x 1.0m to 0.8m x 1.0m. The lower floor columns reached cross sections of 0.9m x 1.0m especially in the corners of the buildings. This is the result of the shear lag effect were increase in axial stress in the corner columns and decrease in the inner columns axial stress.

### 4.3 Comparison Deflections of Structural Systems

Following are the results of the total horizontal deflections for the different types of structural systems by changing the dimensions of the structural members. All the structures are under the allowable drift for 300m tall buildings. Tube in Tube has the smallest drift average of 110.20mm comparing with others, were Frame Tube has a ratio of approximately 1.3 times greater drift than Tube in Tube, and Shear wall Building has a ratio approximately 2.06 times greater drift than Tube in Tube. By this, Tube in Tube is the most efficient in terms of resisting the horizontal deflection. The effects of torsion are very minimal, because of the very low deflection in the Y-direction; however deflection in the Z direction is predominant.

**Table 4.1:** Horizontal Deflection for Shear Wall Building

| Wall dimension (m) | Horizontal Deflection Δ-P (mm) | | | Total (mm) |
|---|---|---|---|---|
| | x | y | z | |
| 0.3 | 207.02 | 2.09 | 48.28 | 257.39 |
| 0.4 | 192.10 | 0.32 | 46.14 | 238.56 |
| 0.5 | 182.49 | 1.57 | 44.50 | 228.56 |
| 0.6 | 142.19 | 0.32 | 42.51 | 185.02 |

**Table 4.2:** Horizontal Deflection for Frame Tube Building

| Column dimension (m) | Horizontal Deflection Δ-P (mm) | | | Total (mm) |
|---|---|---|---|---|
| | x | y | z | |
| 0.5 x 1.0 | 117.37 | 1.34 | 41.05 | 159.76 |
| 0.6 x 1.0 | 104.15 | 0.15 | 36.71 | 141.01 |
| 0.7 x 1.0 | 101.60 | 3.67 | 35.23 | 140.50 |
| 0.8 x 1.0 | 92.44 | 4.74 | 33.11 | 130.29 |

**Table 4.3:** Horizontal Deflection for Tube in Tube Building

| Column dimension (m) | Horizontal Deflection Δ-P (mm) | | | Total (mm) |
|---|---|---|---|---|
| | x | y | z | |
| 0.5 x 1.0 | 89.05 | 2.48 | 47.10 | 138.62 |
| 0.6 x 1.0 | 70.12 | 0.84 | 43.27 | 114.23 |
| 0.7 x 1.0 | 59.97 | 1.49 | 38.59 | 100.05 |
| 0.8 x 1.0 | 51.30 | 0.66 | 35.94 | 87.90 |

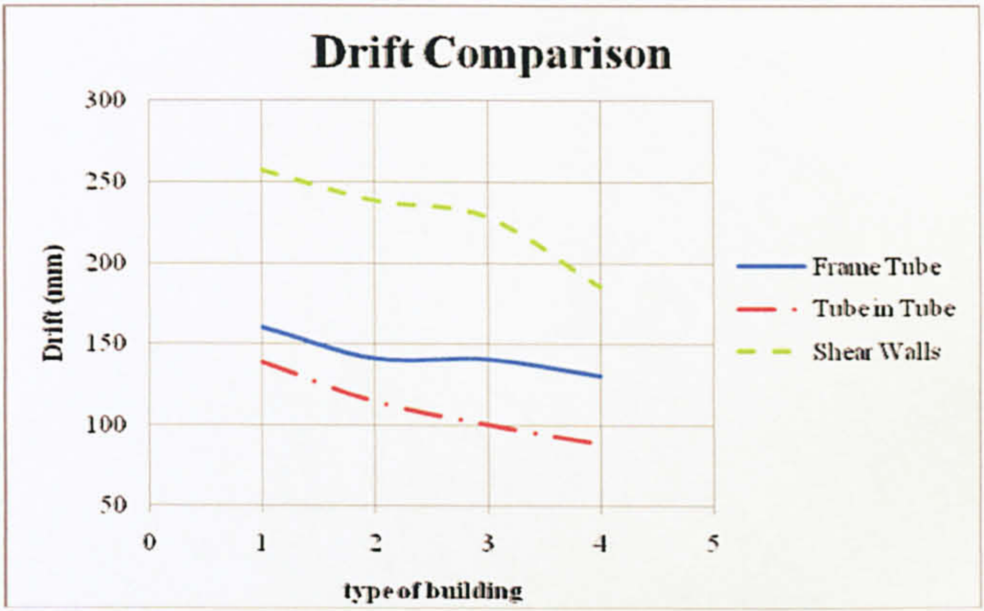



**Figure 4.5:** Drift Comparison

Figure 4.5 shows the comparison of the buildings with the changes in dimensions. The figure shows that all the Tube in Tube designs are the ones with the smaller horizontal deflection, following by the Frame Tube and lastly with the highest horizontal deflections, the Shear Wall. The amount shear walls may have an effect on these deflections, since we just used 2 shear walls in each facade of the building, with 12m length each, to support the wind load, while the Tube system uses closed columns in the entire perimeter of the building.

### 4.4 Economical Analysis

Table 4.4 shows the amount of materials being used for the design of the three Buildings. Cost of materials such as Concrete and Steel Rebar may vary according to the actual economy and also to the contractor and supplier. Attention should be taking to costs, since these Buildings are using high strength materials, which are costly. Since no criteria were mentioned about the type materials, steel A500 was used and improve the resistance against the horizontal deflection and also reduce the member size of the structure.

Taking only the materials cost for the economical analysis, the Tube in Tube would be the most expensive to be build with a steel quantity of 31.440 kg/m$^2$ and a concrete volume of 0.298 m$^3$/m$^2$. Shear Wall Building has a greater amount of Concrete Volume per area, because of the volume of the Shear Walls itself; however it uses the less amount of Steel per area 26.037 kg/m$^3$. Frame Tube is considered the most efficient for 35m/s wind speed in Kuala Lumpur, since it has the average Volume/m$^2$ and Steel/m$^2$ which are 0.291m$^3$/m$^2$ and 26.574kg/m$^2$ and has better deflection than the Shear Wall Building (see Figure 4.9 to 4.11).

**Table 4.4:** Quantity of Materials

| | Shear Wall Building | Frame Tube | Tube in Tube |
|---|---|---|---|
| Concrete Volume (m$^3$) | 78,048.35 | 71,845.58 | 73,425.18 |
| Steel QTY (kg) | 6,581,938.00 | 6,560,153.00 | 7,758,327.00 |
| Superficies (m$^2$) | 252,788.41 | 246862 | 246769.75 |
| Volume/ m$^2$ | 0.309 | 0.291 | 0.298 |
| Steel /m$^2$ | 26.037 | 26.574 | 31.440 |

This research was based on analytical design and comparison made by computer software CYPECAD 2007. For this research the costs involved would be the cost of the license for the modelling design software, where a licence key is approximately RM7,200 equivalent to approximately USD2,200. However for bachelor degree the licence of the software is not a must. This research was not in a grant of specified cost since it is a comparison of the structural systems already designed, were we just needed to compare its deflection under high wind loads.

This research generates 3 products based on design modelling, which are 3 different structural systems: shear wall structural systems, frame tube, and tube in tube structural systems in order to decide which one is the most optimum. This is an intellectual property, where we design considering a design criteria which fulfil our needs of the scope of project.

From table 4.4, the results materials, we can see that the frame tube is the most economical, taking into consideration the volume of concrete which is equal to $0.291m^3/m^2$ and the steel quantity which is 26.574 $kg/m^2$. The Tube in Tube is the most expensive, with 0.298 $m^3/m^2$ of concrete and 31.440 $kg/m^2$ of steel amount, following by the shear wall building with 0.309 $m^3/m^2$ of concrete, and 26.037 $kg/m^2$ of steel. Quality of materials and strength dictates the cost of materials. Since we are using high strength concrete, with grade C50 and high tensile bars of A500, they should be taking into consideration in economical terms since they differ according to the economics of the country and the year.

This design may also be selling to companies or corporate which intend to build such skyscrapers in KLCC, without having the right knowledge. By this we can sell the idea and design in order to save time and money for tendering of consultant companies for design purposes, where the vest option for tall building designs under 35m/s wind speed in Kuala Lumpur will be the Frame Tube.


**Figure 4.6:** Shear Wall Building

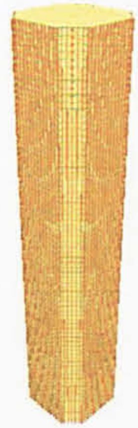


**Figure 4.7:** Frame Tube Building

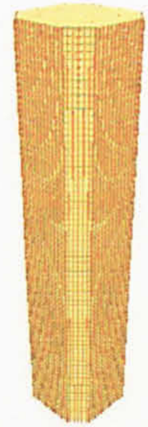


**Figure 4.8:** Tube in Tube Building


**Figure 4.9:** Shear Wall Deflection


**Figure 4.10:** Frame Tube Deflection


**Figure 4.11:** Tube in Tube Deflection

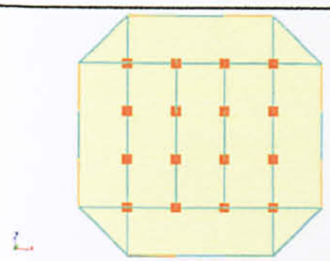


**Figure 4.12:** Shear Wall Plan View

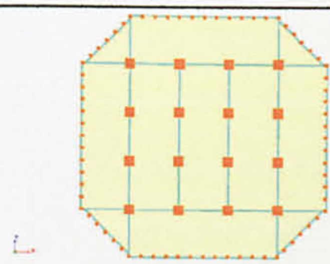


**Figure 4.13:** Frame Tube Plan View

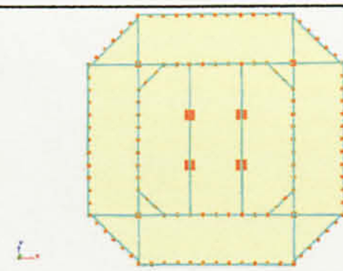


**Figure 4.14:** Tube in Tube Plan View

# CHAPTER 5

# CONCLUSION & RECOMMENDATIONS

## 5.1 Conclusion

The objective of this study was successfully achieved which is to compare three different high-rise structural system in terms of horizontal deflection and to determine the effective structural system under high wind speed in zones such as KLCC, Kuala Lumpur.

From the computational based analysis, results and discussion following conclusions are made:

- Materials strength affect the member sizes of structure as well the horizontal deflection;
- The amount of Shear Wall may influence in the total drift of the Shear Walls Buildings;
- Bigger the member size of the structural systems, smaller the deflection;
- Tube in Tube is the most efficient in terms of lateral deflection comparing to other structural systems;
- Frame Tube is the most efficient in economical terms;
- All the Buildings Deflections are acceptable in the maximum allowed drift of H/500 = 600mm.

## 5.2 Recommendations

Following are the recommendations that would improve the analysis and research of this project:

For the maximum understanding and analysis of such buildings, a detailed situation or criteria should be implemented, since our design just follow the default design just for wind.

- In order to obtain the optimum design for the buildings, earthquake loads and response should have been considered;
- In order to minimise the horizontal drift, an internal core or system should also be taken into consideration;
- The research should be done with more advanced software on tall buildings, which may include the updated design codes.

## REFERENCES


[1] Council of Tall Buildings & Urban Habitat (1980), Tall Building Criteria and Loading, Volume CL

[2] Council of Tall Buildings & Urban Habitat (1980), Tall Building System and Concepts, Volume SC

[3] P. Jayachandran, PhD, M.ASCE (2009), Design of Tall Buildings Preliminary Design and Optimization, University of Hyderabad, Hyderabad, India

[4] Bungale S. Taranath(1997), Steel, Concrete & Composite Design of Tall Buildings, $2^{ND}$ edition, Mc Graw Hill

[5] Mir M Ali & Kyoung Sun Moon, (2007), Structural Developments in Tall Buildings: Current Trends and Future Prospects, University of Illionois, USA.

[6] Structural Systems for Tall Buildings (1995), by Council of Tall Buildings and Urban Habitat

[7] M. Halis Gunel, H. Emre Ilgin, (2006), A proposal for the classification of structural systems of tall buildings, Middle East Technical University, Turkey.

[8] P. Mendis, T. Ngo, N. Haritos, A. Hira, B. Samali, J. Cheung, Monash, Wind Loading on Tall Buildings, The University of Melbourne

[9] NBR 6123 Code, Code for Wind Design, by Associação Brasileira de Normas Tecnicas, June 1988

[10] W. H. Mosley, J. H. Bungey & R. Hulse (1999), Reinforced Concrete Design, $5^{th}$ edition, Palgarve

[11] M. C. Mckenzie (2004), Design of Structural Elements, 1sr edition, Palgrave

[12] http://cypecad.cype.us, (accessed on 10/03/10)

[13] http://theconstructor.org/2009/10/high-rise-structures-2, (accessed on 10/06/10)

# APPENDIX A

**Table A1:** Wind Load Results from CYPECAD

| Level | Wind +X (KN) | Wind –X (KN) | Wind +Y | Wind -Y |
|---|---|---|---|---|
| 75 | 132.359 | -132.359 | 0 | 0 |
| 74 | 263.478 | -263.478 | 0 | 0 |
| 73 | 262.227 | -262.227 | 0 | 0 |
| 72 | 260.964 | -260.964 | 0 | 0 |
| 71 | 259.689 | -259.689 | 0 | 0 |
| 70 | 258.403 | -258.403 | 0 | 0 |
| 69 | 257.105 | -257.105 | 0 | 0 |
| 68 | 255.795 | -255.795 | 0 | 0 |
| 67 | 254.472 | -254.472 | 0 | 0 |
| 66 | 253.136 | -253.136 | 0 | 0 |
| 65 | 251.787 | -251.787 | 0 | 0 |
| 64 | 250.424 | -250.424 | 0 | 0 |
| 63 | 249.048 | -249.048 | 0 | 0 |
| 62 | 247.657 | -247.657 | 0 | 0 |
| 61 | 246.252 | -246.252 | 0 | 0 |
| 60 | 244.831 | -244.831 | 0 | 0 |
| 59 | 243.395 | -243.395 | 0 | 0 |
| 58 | 241.943 | -241.943 | 0 | 0 |
| 57 | 240.475 | -240.475 | 0 | 0 |
| 56 | 238.99 | -238.99 | 0 | 0 |
| 55 | 237.487 | -237.487 | 0 | 0 |
| 54 | 235.967 | -235.967 | 0 | 0 |
| 53 | 234.428 | -234.428 | 0 | 0 |
| 52 | 232.871 | -232.871 | 0 | 0 |
| 51 | 231.293 | -231.293 | 0 | 0 |
| 50 | 229.696 | -229.696 | 0 | 0 |
| 49 | 228.077 | -228.077 | 0 | 0 |
| 48 | 226.437 | -226.437 | 0 | 0 |
| 47 | 224.775 | -224.775 | 0 | 0 |
| 46 | 223.089 | -223.089 | 0 | 0 |
| 45 | 221.38 | -221.38 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| 44 | 219.645 | -219.645 | 0 | 0 |
| 43 | 217.885 | -217.885 | 0 | 0 |
| 42 | 216.098 | -216.098 | 0 | 0 |
| 41 | 214.283 | -214.283 | 0 | 0 |
| 40 | 212.439 | -212.439 | 0 | 0 |
| 39 | 210.565 | -210.565 | 0 | 0 |
| 38 | 208.659 | -208.659 | 0 | 0 |
| 37 | 206.721 | -206.721 | 0 | 0 |
| 36 | 204.748 | -204.748 | 0 | 0 |
| 35 | 202.739 | -202.739 | 0 | 0 |
| 34 | 200.693 | -200.693 | 0 | 0 |
| 33 | 198.607 | -198.607 | 0 | 0 |
| 32 | 196.479 | -196.479 | 0 | 0 |
| 31 | 194.308 | -194.308 | 0 | 0 |
| 30 | 192.091 | -192.091 | 0 | 0 |
| 29 | 189.825 | -189.825 | 0 | 0 |
| 28 | 187.508 | -187.508 | 0 | 0 |
| 27 | 185.136 | -185.136 | 0 | 0 |
| 26 | 182.707 | -182.707 | 0 | 0 |
| 25 | 180.216 | -180.216 | 0 | 0 |
| 24 | 177.659 | -177.659 | 0 | 0 |
| 23 | 175.032 | -175.032 | 0 | 0 |
| 22 | 172.33 | -172.33 | 0 | 0 |
| 21 | 169.547 | -169.547 | 0 | 0 |
| 20 | 166.676 | -166.676 | 0 | 0 |
| 19 | 163.711 | -163.711 | 0 | 0 |
| 18 | 160.642 | -160.642 | 0 | 0 |
| 17 | 157.46 | -157.46 | 0 | 0 |
| 16 | 154.154 | -154.154 | 0 | 0 |
| 15 | 150.711 | -150.711 | 0 | 0 |
| 14 | 147.116 | -147.116 | 0 | 0 |
| 13 | 143.349 | -143.349 | 0 | 0 |
| 12 | 139.389 | -139.389 | 0 | 0 |
| 11 | 135.208 | -135.208 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| 10 | 130.772 | -130.772 | 0 | 0 |
| 9 | 126.037 | -126.037 | 0 | 0 |
| 8 | 120.947 | -120.947 | 0 | 0 |
| 7 | 115.424 | -115.424 | 0 | 0 |
| 6 | 109.362 | -109.362 | 0 | 0 |
| 5 | 102.601 | -102.601 | 0 | 0 |
| 4 | 94.893 | -94.893 | 0 | 0 |
| 3 | 85.804 | -85.804 | 0 | 0 |
| 2 | 74.452 | -74.452 | 0 | 0 |
| 1 | 58.414 | -58.414 | 0 | 0 |

**Table A2:** Columns Horizontal Deflection for 30cm Shear Wall Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.2070201 | 0.0020871 | 0.0482789 | 257.39 |
| 280 | 0.1988457 | 0.0018533 | 0.047509 | 248.21 |
| 260 | 0.1896896 | 0.0016241 | 0.0454365 | 236.75 |
| 240 | 0.1791698 | 0.0014053 | 0.0420097 | 222.58 |
| 220 | 0.167348 | 0.0012085 | 0.0398356 | 208.39 |
| 200 | 0.1540241 | 0.0010245 | 0.0369725 | 192.02 |
| 180 | 0.1392156 | 0.0008504 | 0.0333964 | 173.46 |
| 160 | 0.1231597 | 0.0006886 | 0.0290768 | 152.93 |
| 140 | 0.1063099 | 0.0005448 | 0.0261915 | 133.05 |
| 120 | 0.0886478 | 0.0004151 | 0.0228243 | 111.89 |
| 100 | 0.0703881 | 0.0002991 | 0.0189664 | 89.65 |
| 80 | 0.0520734 | 0.0001996 | 0.0146091 | 66.88 |
| 60 | 0.0345931 | 0.0001204 | 0.0114759 | 46.19 |
| 40 | 0.0186302 | 5.935E-05 | 0.0079863 | 26.68 |
| 20 | 0.0059326 | 1.762E-05 | 0.0041528 | 10.10 |
| Found. | 0 | 0 | 0 | 0.00 |

**Table A3:** Columns Horizontal Deflection for 40cm Shear Wall Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.1921009 | 0.0003187 | 0.0461399 | 238.56 |
| 280 | 0.1844114 | 0.0003019 | 0.0454112 | 230.12 |
| 260 | 0.1758765 | 0.0002833 | 0.0434456 | 219.61 |
| 240 | 0.166121 | 0.0002616 | 0.0401945 | 206.58 |
| 220 | 0.1551174 | 0.0002356 | 0.0381282 | 193.48 |
| 200 | 0.1427115 | 0.0002055 | 0.0354025 | 178.32 |
| 180 | 0.1289236 | 0.0001731 | 0.0319945 | 161.09 |
| 160 | 0.1139488 | 0.0001399 | 0.0278746 | 141.96 |
| 140 | 0.0981546 | 0.0001067 | 0.0251193 | 123.38 |
| 120 | 0.0815995 | 7.552E-05 | 0.0218995 | 103.57 |
| 100 | 0.0645321 | 4.927E-05 | 0.0182068 | 82.79 |
| 80 | 0.0474781 | 2.897E-05 | 0.0140323 | 61.54 |
| 60 | 0.031265 | 1.465E-05 | 0.0110275 | 42.31 |
| 40 | 0.0166319 | 6.28E-06 | 0.0076776 | 24.32 |
| 20 | 0.0052049 | 1.54E-06 | 0.0039944 | 9.20 |
| 0 | 0 | 0 | 0 | 0.00 |

**Table A4:** Columns Horizontal Deflection for 50cm Shear Wall Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.1824879 | 0.0015727 | 0.0445038 | 228.56 |
| 280 | 0.1747789 | 0.0013981 | 0.043807 | 219.98 |
| 260 | 0.1663351 | 0.0012273 | 0.0419268 | 209.49 |
| 240 | 0.1568161 | 0.0010642 | 0.0388156 | 196.70 |
| 220 | 0.1461825 | 0.0009158 | 0.0368343 | 183.93 |
| 200 | 0.1342766 | 0.0007762 | 0.0342157 | 169.27 |
| 180 | 0.1211065 | 0.0006438 | 0.0309377 | 152.69 |
| 160 | 0.1068445 | 0.0005202 | 0.0269707 | 134.34 |
| 140 | 0.0918201 | 0.0004091 | 0.024314 | 116.54 |
| 120 | 0.0761128 | 0.0003089 | 0.0212055 | 97.63 |
| 100 | 0.0599791 | 0.0002199 | 0.017637 | 77.84 |
| 80 | 0.0439259 | 0.0001443 | 0.0135998 | 57.67 |
| 60 | 0.0287351 | 0.0000847 | 0.0106912 | 39.51 |
| 40 | 0.0151511 | 4.014E-05 | 0.0074459 | 22.64 |
| 20 | 0.0046837 | 1.121E-05 | 0.0038754 | 8.57 |
| 0 | 0 | 0 | 0 | 0.00 |

**Table A5:** Columns Horizontal Deflection for 60cm Shear Wall Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.1421872 | 0.0003213 | 0.0425099 | 185.02 |
| 280 | 0.1360353 | 0.0003018 | 0.0418379 | 178.18 |
| 260 | 0.1293193 | 0.0002807 | 0.0400278 | 169.63 |
| 240 | 0.1217672 | 0.0002569 | 0.0370329 | 159.06 |
| 220 | 0.1133265 | 0.0002293 | 0.035124 | 148.68 |
| 200 | 0.1038945 | 0.0001984 | 0.0325998 | 136.69 |
| 180 | 0.0934913 | 0.0001659 | 0.0294402 | 123.10 |
| 160 | 0.0822554 | 0.0001332 | 0.025617 | 108.01 |
| 140 | 0.0704374 | 0.0001013 | 0.0230568 | 93.60 |
| 120 | 0.0581376 | 7.176E-05 | 0.0200619 | 78.27 |
| 100 | 0.0455848 | 4.675E-05 | 0.0166256 | 62.26 |
| 80 | 0.033193 | 2.733E-05 | 0.0130318 | 46.25 |
| 60 | 0.021535 | 1.369E-05 | 0.0102288 | 31.78 |
| 40 | 0.0112331 | 5.65E-06 | 0.0071053 | 18.34 |
| 20 | 0.0034156 | 1.34E-06 | 0.0036711 | 7.09 |
| 0 | 0 | 0 | 0 | 0.00 |

**Table A6:** Horizontal Deflection for 0.5m x 1.0m Columns in Frame Tube Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.1173712 | 0.0013377 | 0.0410467 | 159.76 |
| 280 | 0.1140877 | 0.0012125 | 0.0408395 | 156.14 |
| 260 | 0.1096368 | 0.0010874 | 0.0402441 | 150.97 |
| 240 | 0.1040162 | 0.000965 | 0.0392538 | 144.24 |
| 220 | 0.0977683 | 0.0008246 | 0.0379032 | 136.50 |
| 200 | 0.0905843 | 0.0006902 | 0.0361919 | 127.47 |
| 180 | 0.082484 | 0.0005637 | 0.0341083 | 117.16 |
| 160 | 0.0736012 | 0.0004483 | 0.0316578 | 105.71 |
| 140 | 0.0645331 | 0.0003537 | 0.0288821 | 93.77 |
| 120 | 0.0549191 | 0.00027 | 0.0257708 | 80.96 |
| 100 | 0.0447905 | 0.0001976 | 0.0222914 | 67.28 |
| 80 | 0.0344213 | 0.0001395 | 0.0184256 | 52.99 |
| 60 | 0.0243168 | 9.825E-05 | 0.0141661 | 38.58 |
| 40 | 0.0144459 | 6.416E-05 | 0.0094346 | 23.94 |
| 20 | 0.0055381 | 2.428E-05 | 0.0049991 | 10.56 |
| 0 | 0 | 0 | 0 | 0.00 |

**Table A7:** Horizontal Deflection for 0.6m x 1.0m Columns in Frame Tube Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.1041459 | 0.0001457 | 0.0367145 | 141.01 |
| 280 | 0.1013301 | 0.0001092 | 0.0365336 | 137.97 |
| 260 | 0.0974894 | 0.0000735 | 0.0360106 | 133.57 |
| 240 | 0.092625 | 4.144E-05 | 0.0351408 | 127.81 |
| 220 | 0.0871452 | 3.522E-05 | 0.0339475 | 121.13 |
| 200 | 0.0808352 | 3.262E-05 | 0.0324275 | 113.30 |
| 180 | 0.0737172 | 3.435E-05 | 0.0305728 | 104.32 |
| 160 | 0.0658957 | 3.946E-05 | 0.0283885 | 94.32 |
| 140 | 0.0578362 | 3.807E-05 | 0.0259053 | 83.78 |
| 120 | 0.0492798 | 4.025E-05 | 0.023113 | 72.43 |
| 100 | 0.0402621 | 4.754E-05 | 0.0199846 | 60.29 |
| 80 | 0.0310185 | 5.834E-05 | 0.0165008 | 47.58 |
| 60 | 0.0219964 | 6.677E-05 | 0.0126389 | 34.70 |
| 40 | 0.0131525 | 6.532E-05 | 0.0085482 | 21.77 |
| 20 | 0.005095 | 2.733E-05 | 0.004336 | 9.46 |
| 0 | 0 | 0 | 0 | 0.00 |

**Table A8:** Horizontal Deflection for 0.7m x 1.0m Columns in Frame Tube Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.1015957 | 0.0036718 | 0.0352295 | 140.50 |
| 280 | 0.0985804 | 0.0034604 | 0.0350585 | 137.10 |
| 260 | 0.0946264 | 0.003238 | 0.0345626 | 132.43 |
| 240 | 0.0897383 | 0.0029981 | 0.0337389 | 126.48 |
| 220 | 0.0842962 | 0.0027606 | 0.0326052 | 119.66 |
| 200 | 0.0780798 | 0.0025034 | 0.0311577 | 111.74 |
| 180 | 0.0711118 | 0.0022272 | 0.0293902 | 102.73 |
| 160 | 0.0634938 | 0.0019343 | 0.0273084 | 92.74 |
| 140 | 0.0556692 | 0.001628 | 0.0249383 | 82.24 |
| 120 | 0.0473914 | 0.0013175 | 0.022272 | 70.98 |
| 100 | 0.0387041 | 0.0010107 | 0.0192898 | 59.00 |
| 80 | 0.02982 | 0.0007171 | 0.0159815 | 46.52 |
| 60 | 0.0211379 | 0.000449 | 0.0123425 | 33.93 |
| 40 | 0.0126451 | 0.0002249 | 0.0083196 | 21.19 |
| 20 | 0.0049074 | 6.858E-05 | 0.0043919 | 9.37 |
| 0 | 0 | 0 | 0 | 0.00 |

**Table A9:** Horizontal Deflection for 0.8m x 1.0m Columns in Frame Tube Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.0924436 | 0.0047362 | 0.0331104 | 130.29 |
| 280 | 0.0897609 | 0.0044013 | 0.0329511 | 127.11 |
| 260 | 0.0862369 | 0.0040542 | 0.0324883 | 122.78 |
| 240 | 0.081872 | 0.0036955 | 0.0317205 | 117.29 |
| 220 | 0.0769763 | 0.0033425 | 0.0306609 | 110.98 |
| 200 | 0.0713739 | 0.0029786 | 0.029305 | 103.66 |
| 180 | 0.065086 | 0.0026065 | 0.0276484 | 95.34 |
| 160 | 0.0581995 | 0.0022302 | 0.0256969 | 86.13 |
| 140 | 0.0510904 | 0.001851 | 0.0234719 | 76.41 |
| 120 | 0.0435568 | 0.00148 | 0.0209664 | 66.00 |
| 100 | 0.0356411 | 0.0011263 | 0.0181645 | 54.93 |
| 80 | 0.0275255 | 0.0008002 | 0.0150583 | 43.38 |
| 60 | 0.0195606 | 0.0005108 | 0.0116438 | 31.72 |
| 40 | 0.0117416 | 0.0002729 | 0.0078758 | 19.89 |
| 20 | 0.0045822 | 9.403E-05 | 0.0041507 | 8.83 |
| 0 | 0 | 0 | 0 | 0.00 |

**Table A10:** Horizontal Deflection for 0.5m x 1.0m Columns in Tube in Tube Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.0890512 | 0.0024758 | 0.0470963 | 138.62 |
| 280 | 0.0860351 | 0.0022359 | 0.0468758 | 135.15 |
| 260 | 0.0823946 | 0.0019975 | 0.0462478 | 130.64 |
| 240 | 0.0781089 | 0.0017628 | 0.0451971 | 125.07 |
| 220 | 0.0732061 | 0.0015355 | 0.0437106 | 118.45 |
| 200 | 0.0677135 | 0.0013149 | 0.0417777 | 110.81 |
| 180 | 0.061672 | 0.0011024 | 0.03939 | 102.16 |
| 160 | 0.0551326 | 0.0008989 | 0.0365414 | 92.57 |
| 140 | 0.0481587 | 0.0007036 | 0.0332317 | 82.09 |
| 120 | 0.0408776 | 0.0005234 | 0.0294665 | 70.87 |
| 100 | 0.0333363 | 0.0003746 | 0.0252025 | 58.91 |
| 80 | 0.0256299 | 0.0002436 | 0.0203571 | 46.23 |
| 60 | 0.0179246 | 0.0001415 | 0.0150765 | 33.14 |
| 40 | 0.0105069 | 0.000064 | 0.0103672 | 20.94 |
| 20 | 0.0044902 | 0.000015 | 0.0052256 | 9.73 |
| 0 | 0 | 0 | 0 | 0.00 |

**Table A11:** Horizontal Deflection for 0.6m x 1.0m Columns in Tube in Tube Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.0701155 | 0.0008385 | 0.0432717 | 114.23 |
| 280 | 0.0678213 | 0.0007542 | 0.0430692 | 111.64 |
| 260 | 0.0650448 | 0.0006705 | 0.0424945 | 108.21 |
| 240 | 0.0617761 | 0.0005886 | 0.0415373 | 103.90 |
| 220 | 0.0580255 | 0.0005109 | 0.0401887 | 98.73 |
| 200 | 0.0538258 | 0.0004361 | 0.0384421 | 92.70 |
| 180 | 0.0492092 | 0.0003649 | 0.0362928 | 85.87 |
| 160 | 0.0442162 | 0.0002976 | 0.0337399 | 78.25 |
| 140 | 0.0389052 | 0.0002338 | 0.0307913 | 69.93 |
| 120 | 0.0333751 | 0.000175 | 0.0274587 | 61.01 |
| 100 | 0.0276301 | 0.0001225 | 0.0237308 | 51.48 |
| 80 | 0.0217525 | 7.719E-05 | 0.0196067 | 41.44 |
| 60 | 0.0158447 | 3.995E-05 | 0.0150678 | 30.95 |
| 40 | 0.0099863 | 1.229E-05 | 0.010051 | 20.05 |
| 20 | 0.0043455 | 6.3E-07 | 0.0052638 | 9.61 |
| 0 | 0 | 0 | 0 | 0.00 |

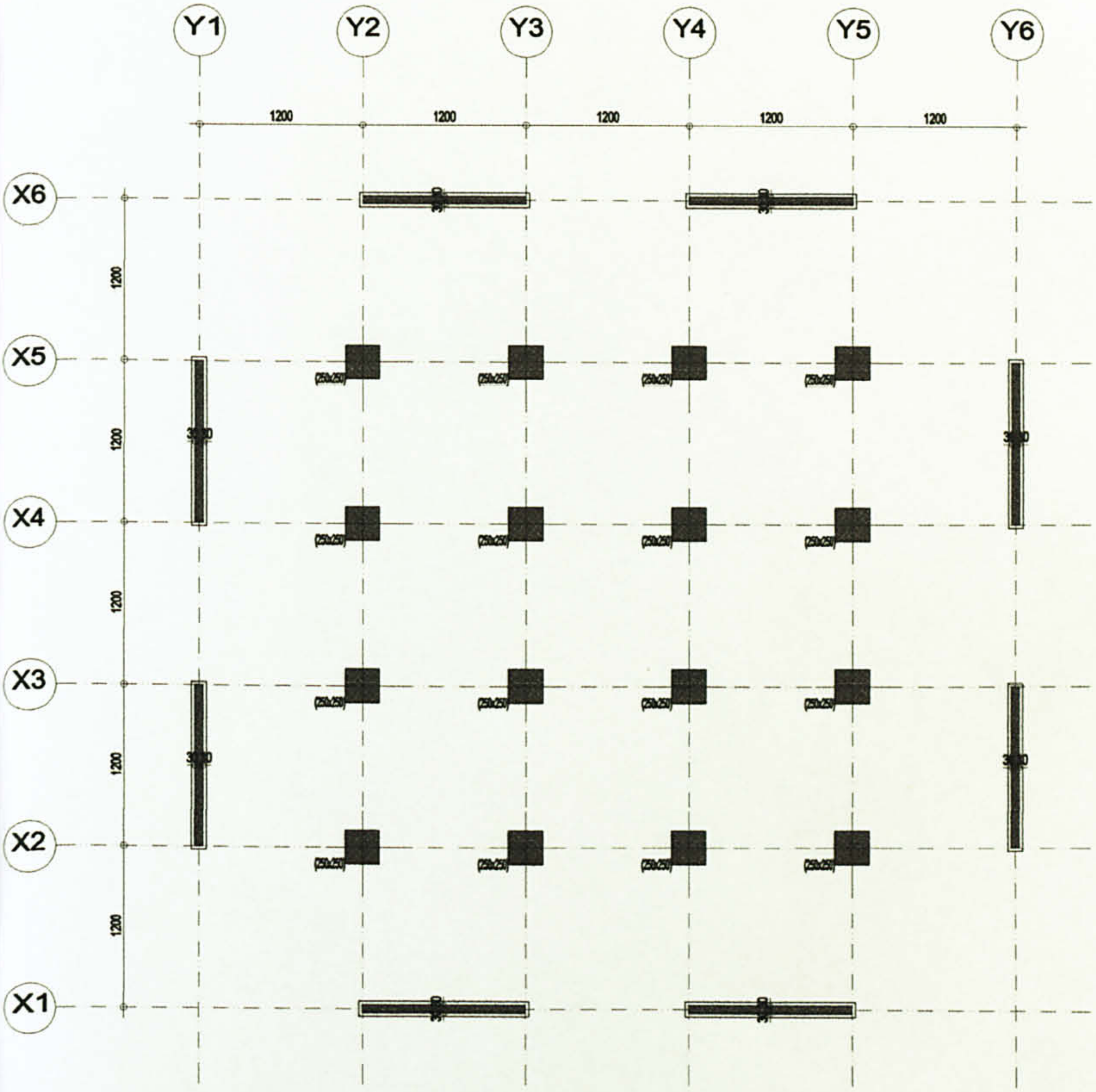
**Table A12:** Horizontal Deflection for 0.7m x 1.0m Columns in Tube in Tube Building

| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.0599701 | 0.0014852 | 0.0385939 | 100.05 |
| 280 | 0.057778 | 0.0013325 | 0.0384163 | 97.53 |
| 260 | 0.0551953 | 0.0011816 | 0.0379088 | 94.29 |
| 240 | 0.0522239 | 0.0010338 | 0.0370641 | 90.32 |
| 220 | 0.0488836 | 0.0008921 | 0.0358755 | 85.65 |
| 200 | 0.0451937 | 0.0007562 | 0.0343384 | 80.29 |
| 180 | 0.0411821 | 0.0006275 | 0.0324495 | 74.26 |
| 160 | 0.0368826 | 0.0005072 | 0.0302087 | 67.60 |
| 140 | 0.0323366 | 0.0003959 | 0.0276233 | 60.36 |
| 120 | 0.0276333 | 0.0002959 | 0.0247037 | 52.63 |
| 100 | 0.0227812 | 0.0002081 | 0.0214441 | 44.43 |
| 80 | 0.0178634 | 0.0001342 | 0.0178504 | 35.85 |
| 60 | 0.0129745 | 7.505E-05 | 0.0139241 | 26.97 |
| 40 | 0.0081638 | 0.0000314 | 0.0096566 | 17.85 |
| 20 | 0.0035686 | 7.27E-06 | 0.0050296 | 8.61 |
| 0 | 0 | 0 | 0 | 0.00 |

**Table A13:** Horizontal Deflection for 0.8m x 1.0m Columns in Tube in Tube Building

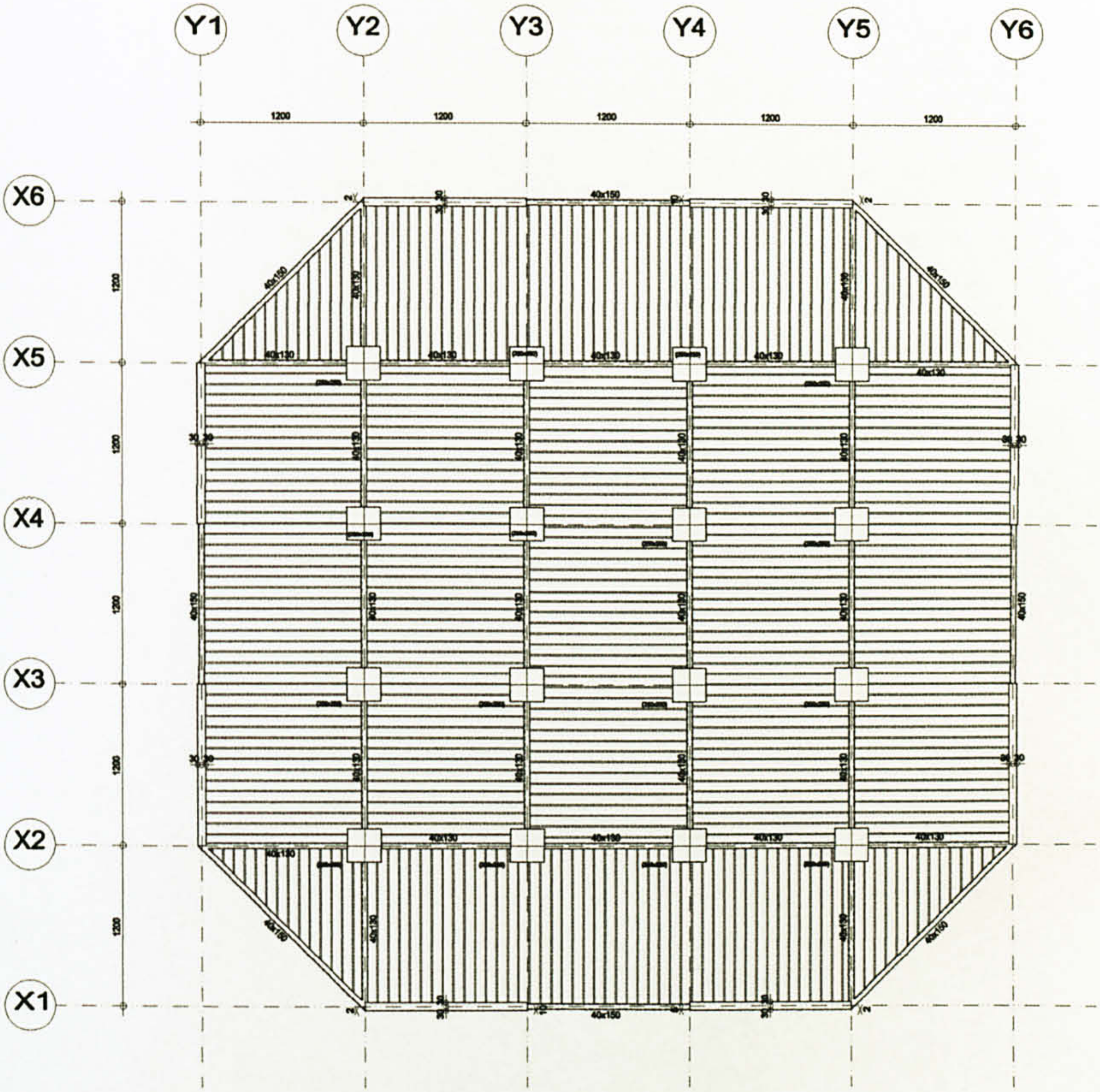
| Height (m) | Defl. X (m) | Defl. Y (m) | Defl. Z (m) | Total (mm) |
|---|---|---|---|---|
| 300 | 0.0513006 | 0.0006625 | 0.0359404 | 87.90 |
| 280 | 0.0493642 | 0.0005951 | 0.035773 | 85.73 |
| 260 | 0.0470941 | 0.0005287 | 0.0352976 | 82.92 |
| 240 | 0.0444996 | 0.0004639 | 0.0345082 | 79.47 |
| 220 | 0.0415978 | 0.0004028 | 0.0333994 | 75.40 |
| 200 | 0.0384062 | 0.0003444 | 0.0319672 | 70.72 |
| 180 | 0.0349491 | 0.0002896 | 0.0302088 | 65.45 |
| 160 | 0.0312565 | 0.0002387 | 0.0281241 | 59.62 |
| 140 | 0.0273647 | 0.0001916 | 0.0257186 | 53.27 |
| 120 | 0.0233525 | 0.0001499 | 0.023001 | 46.50 |
| 100 | 0.0192267 | 0.0001142 | 0.0199663 | 39.31 |
| 80 | 0.0150593 | 8.549E-05 | 0.0166195 | 31.76 |
| 60 | 0.010929 | 6.441E-05 | 0.012962 | 23.96 |
| 40 | 0.006881 | 4.778E-05 | 0.0089868 | 15.92 |
| 20 | 0.0030271 | 2.566E-05 | 0.0046788 | 7.73 |
| 0 | 0 | 0 | 0 | 0.00 |

# APPENDIX B

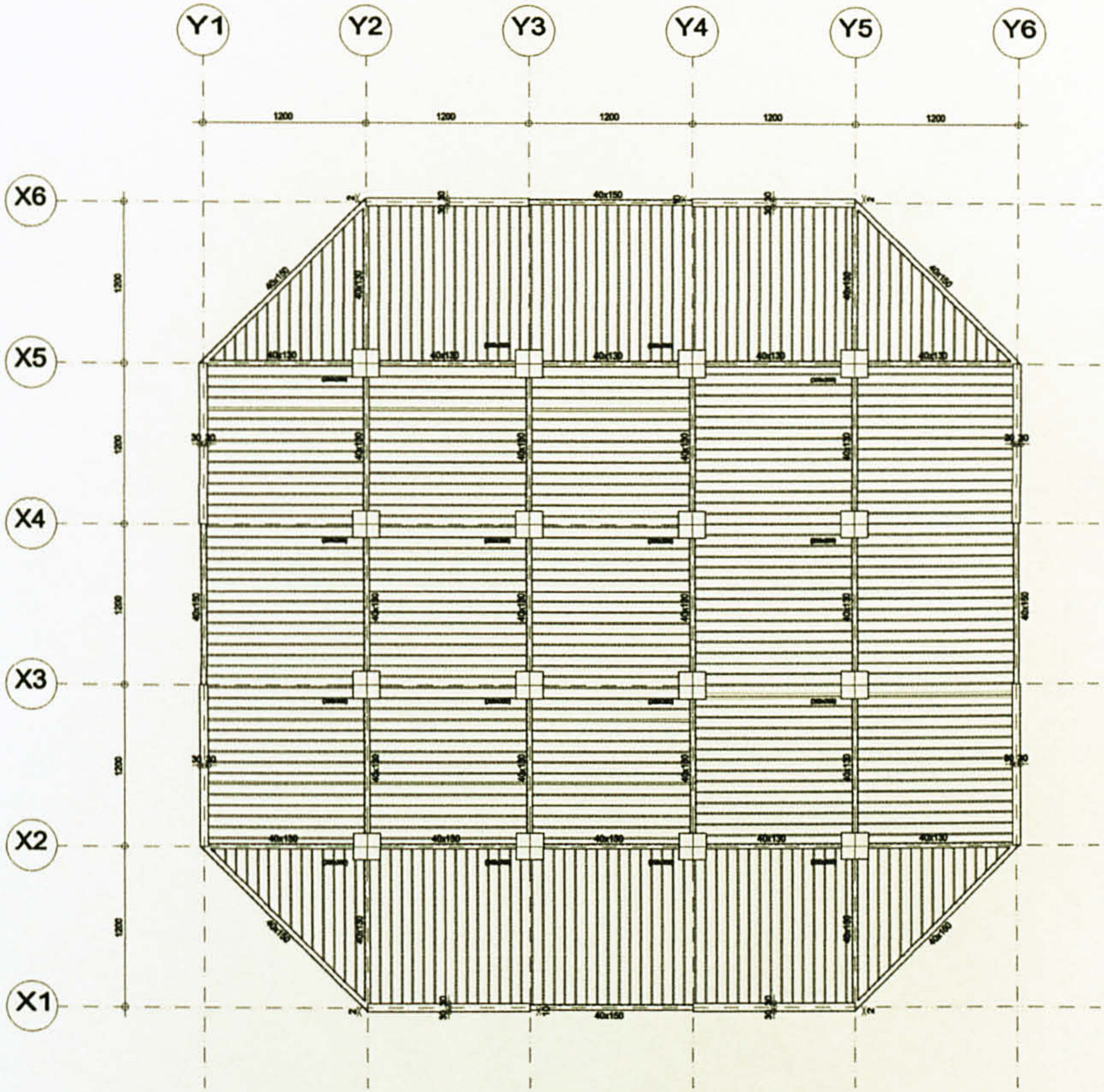



Foundation

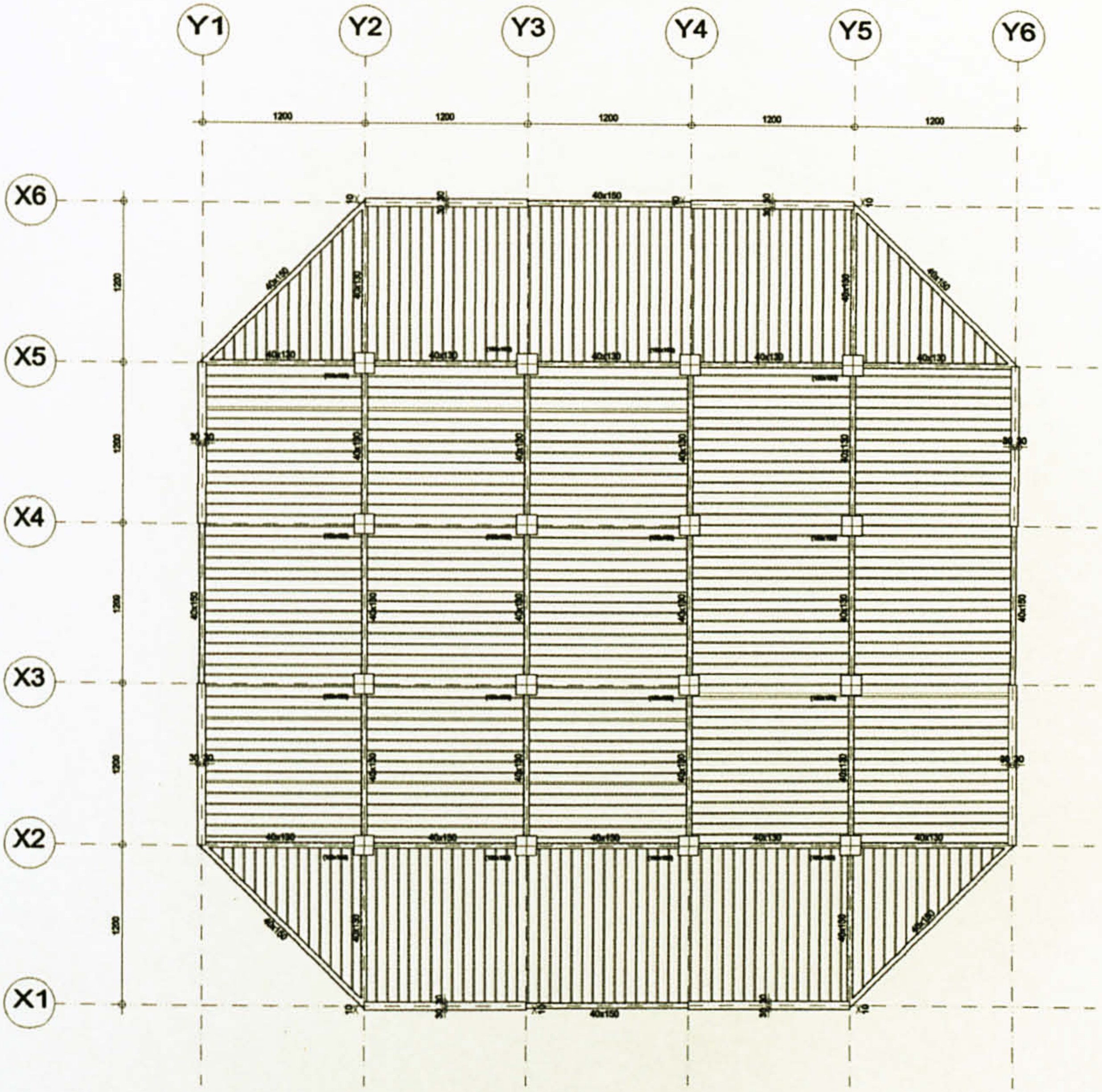
Foundation
Plan
Scale: 1:500



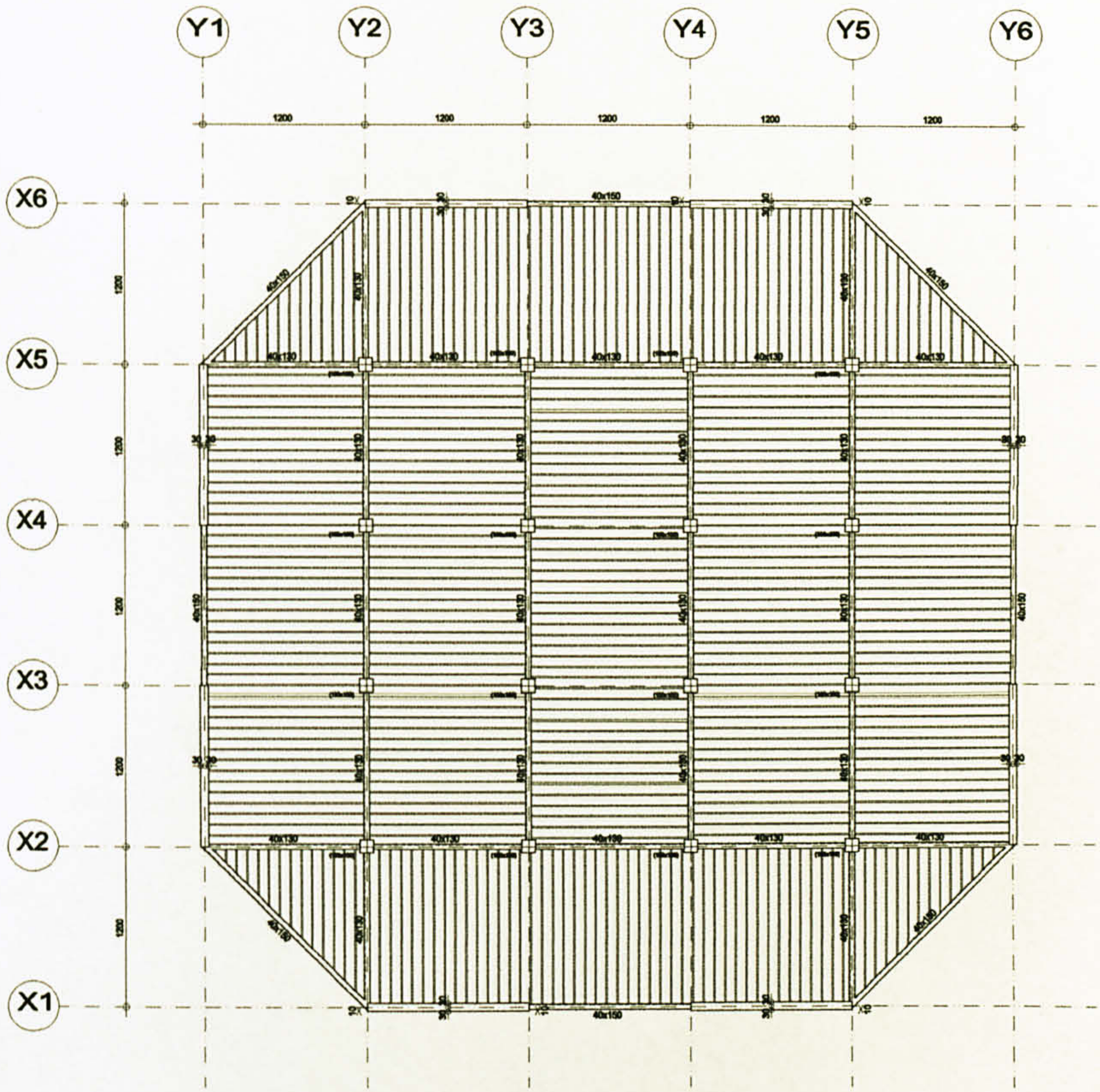

stories 1to 21
**Plan**
Scale: 1:500



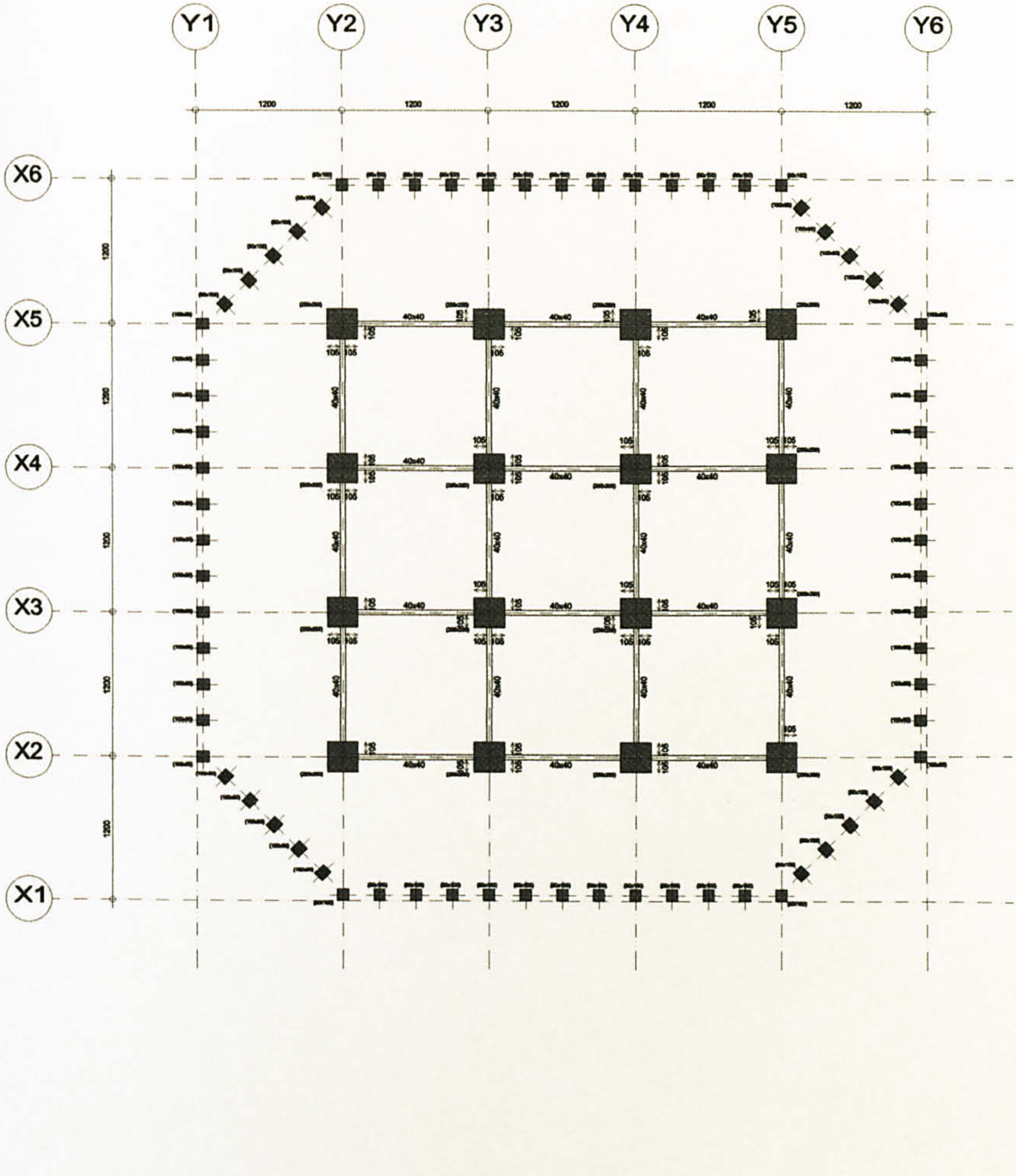

stories 21 to 40
**Plan**
Scale: 1:500



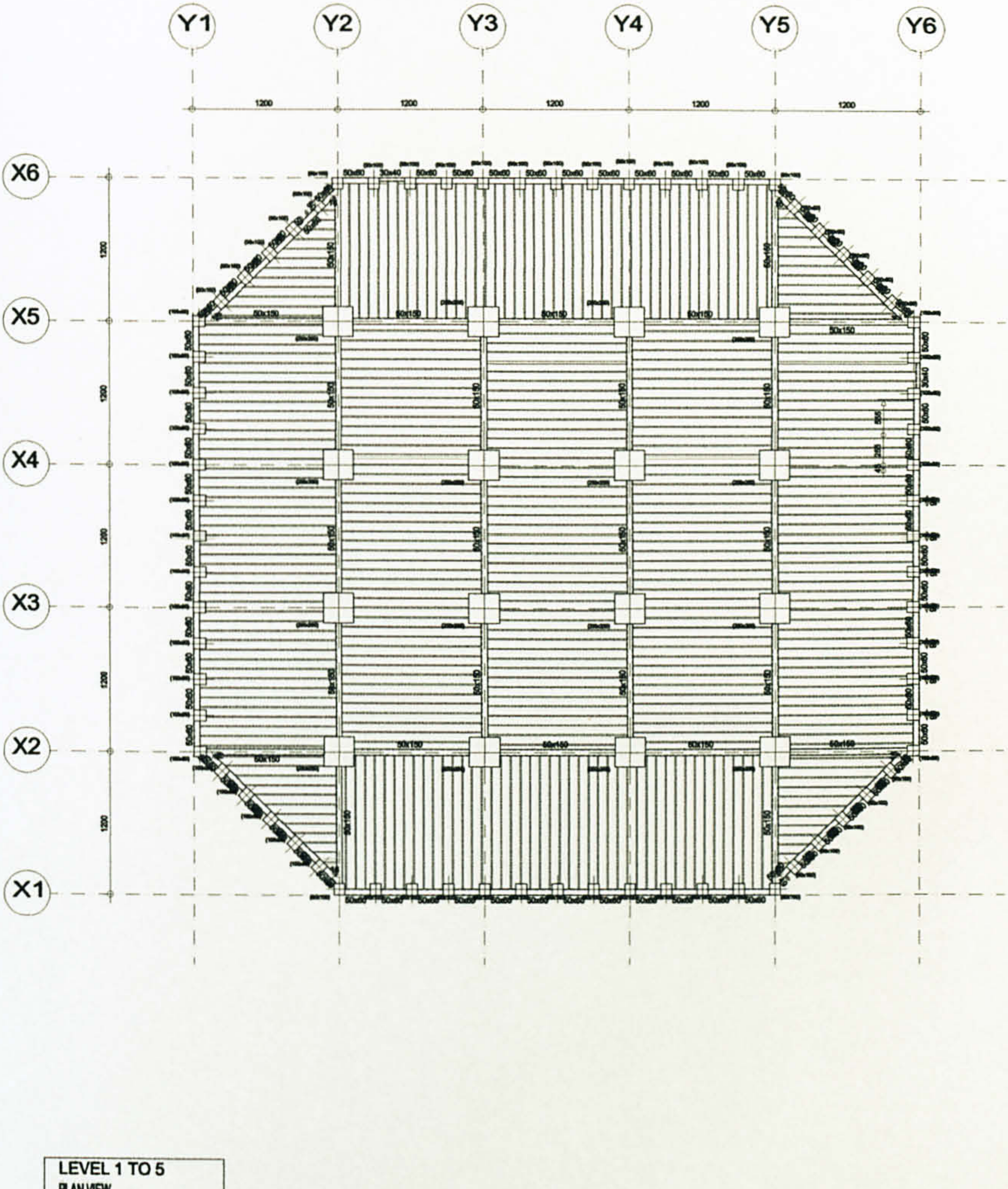

stories 41 to 60
Plan View
scale: 1:500



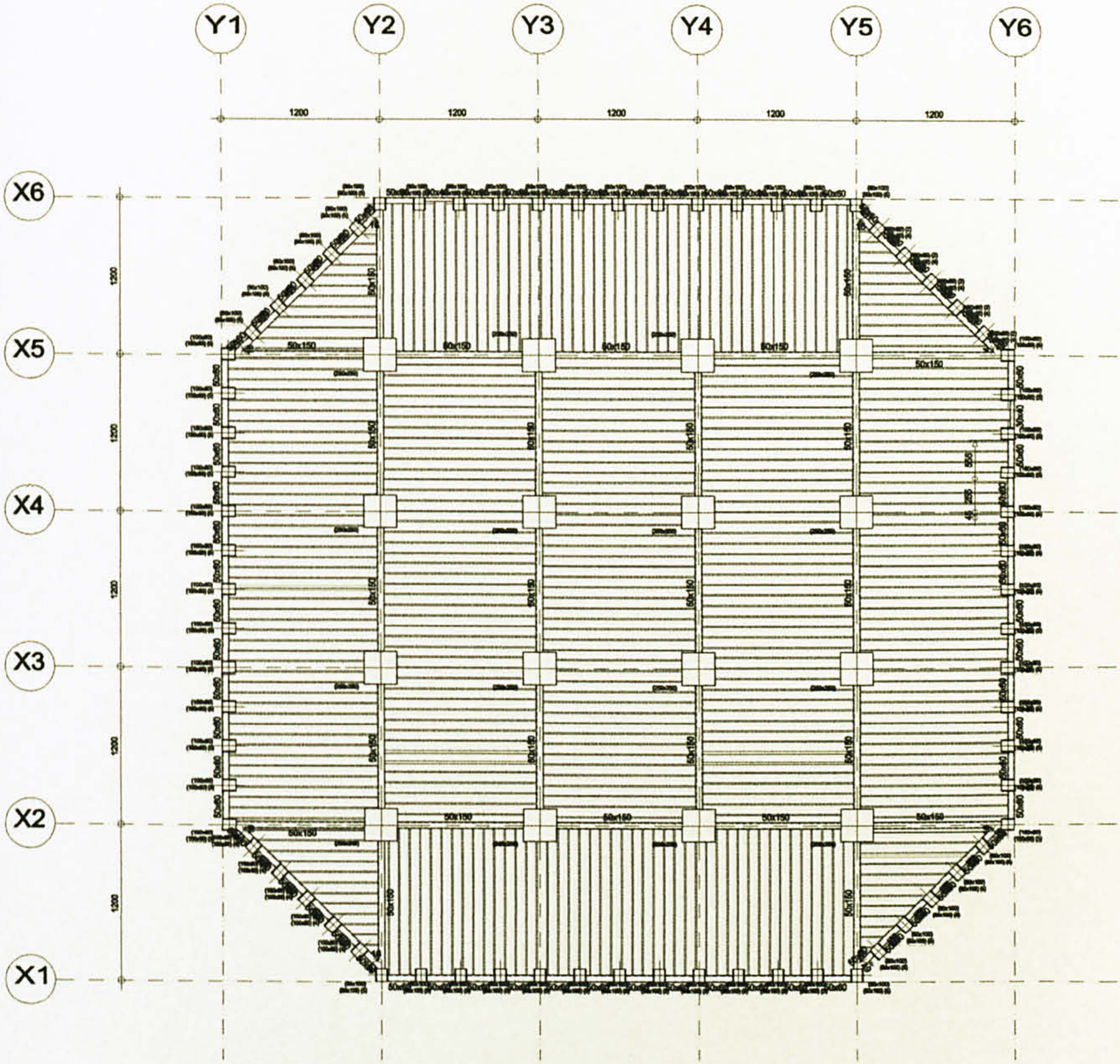

stories 61 to 75
Plan View
Scale: 1:500



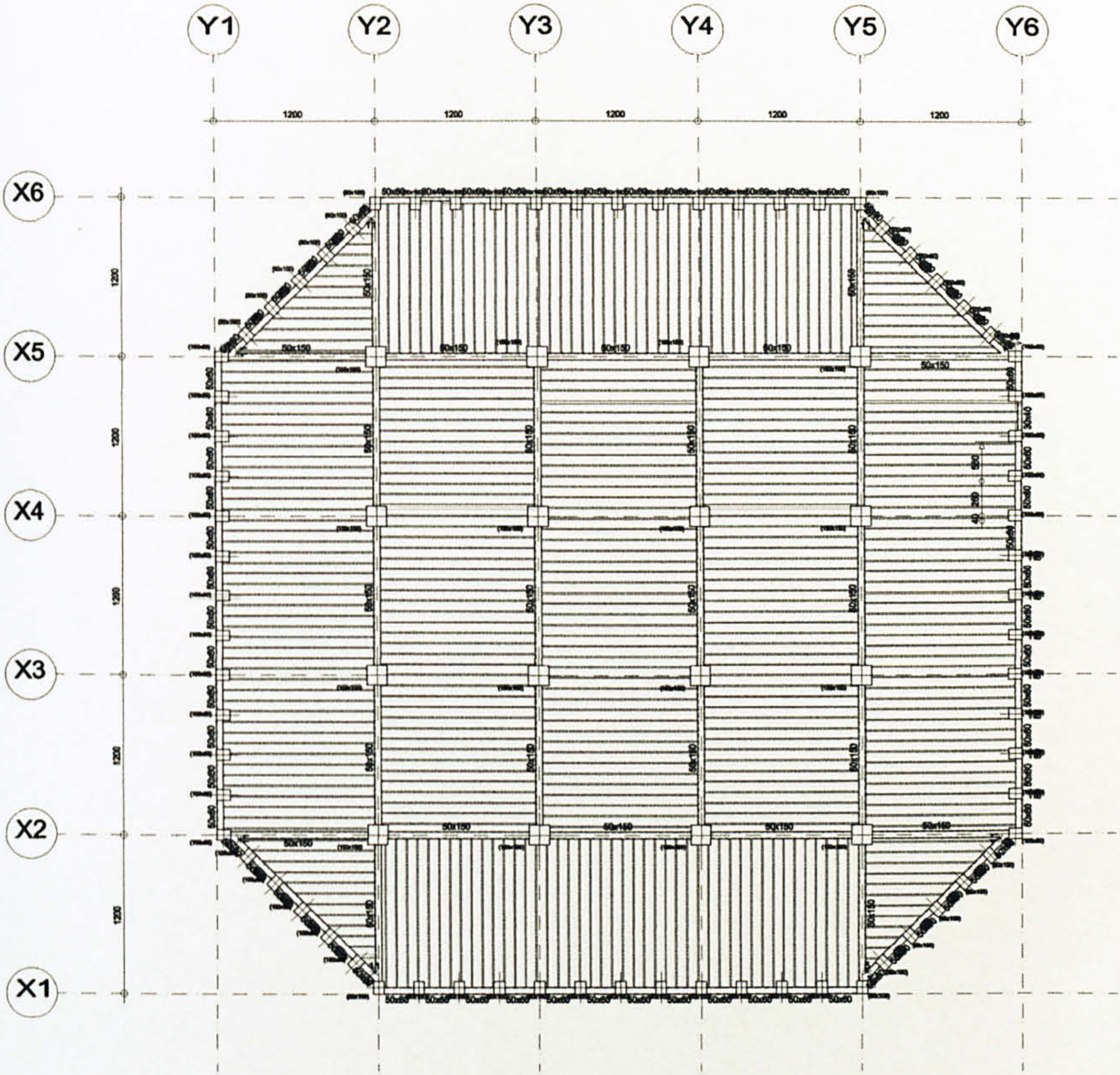

FOUNDATION
PLAN VIEW
SCALE: 1:500



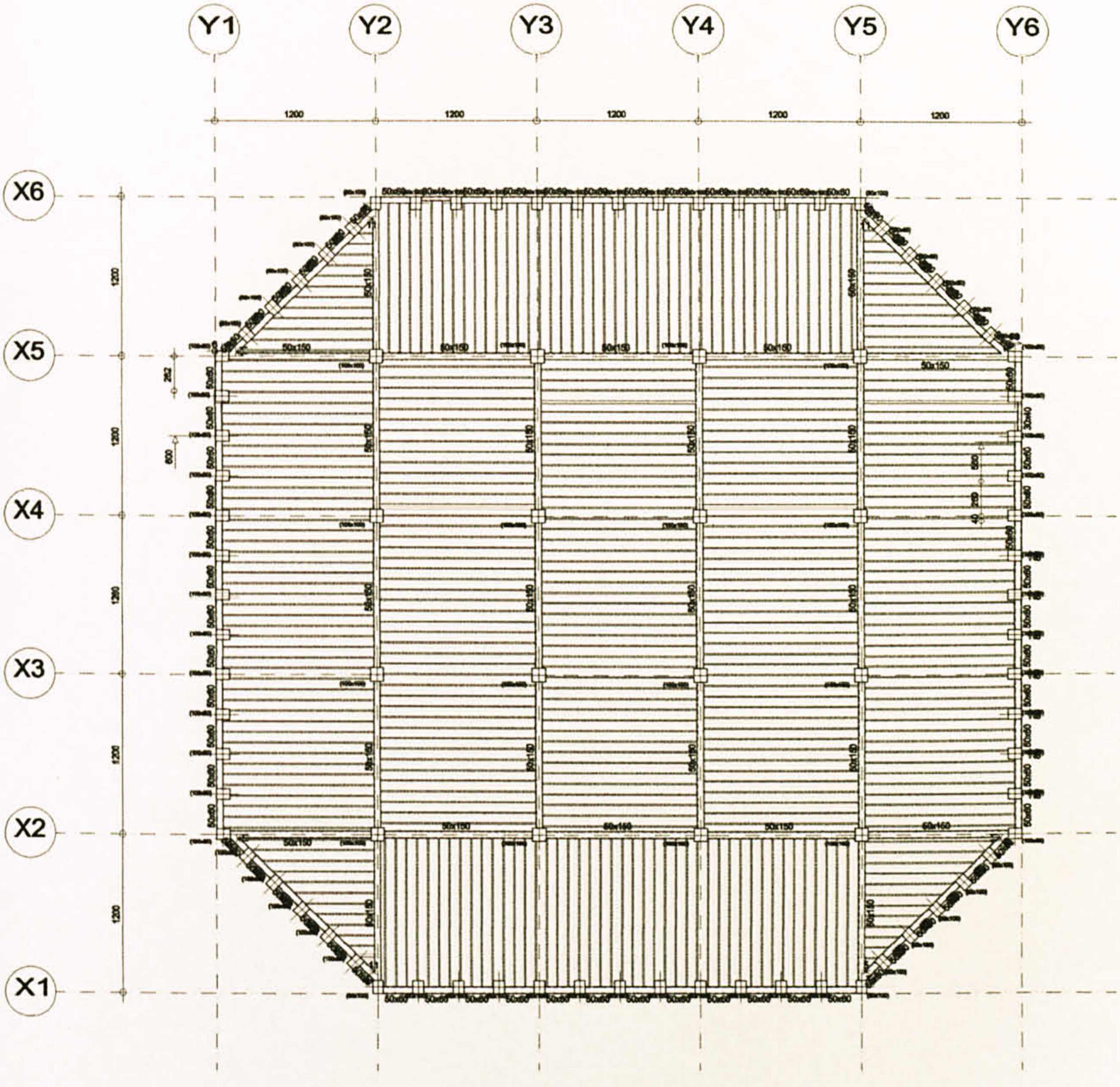

LEVEL 1 TO 5
PLAN VIEW
SCALE: 1:500



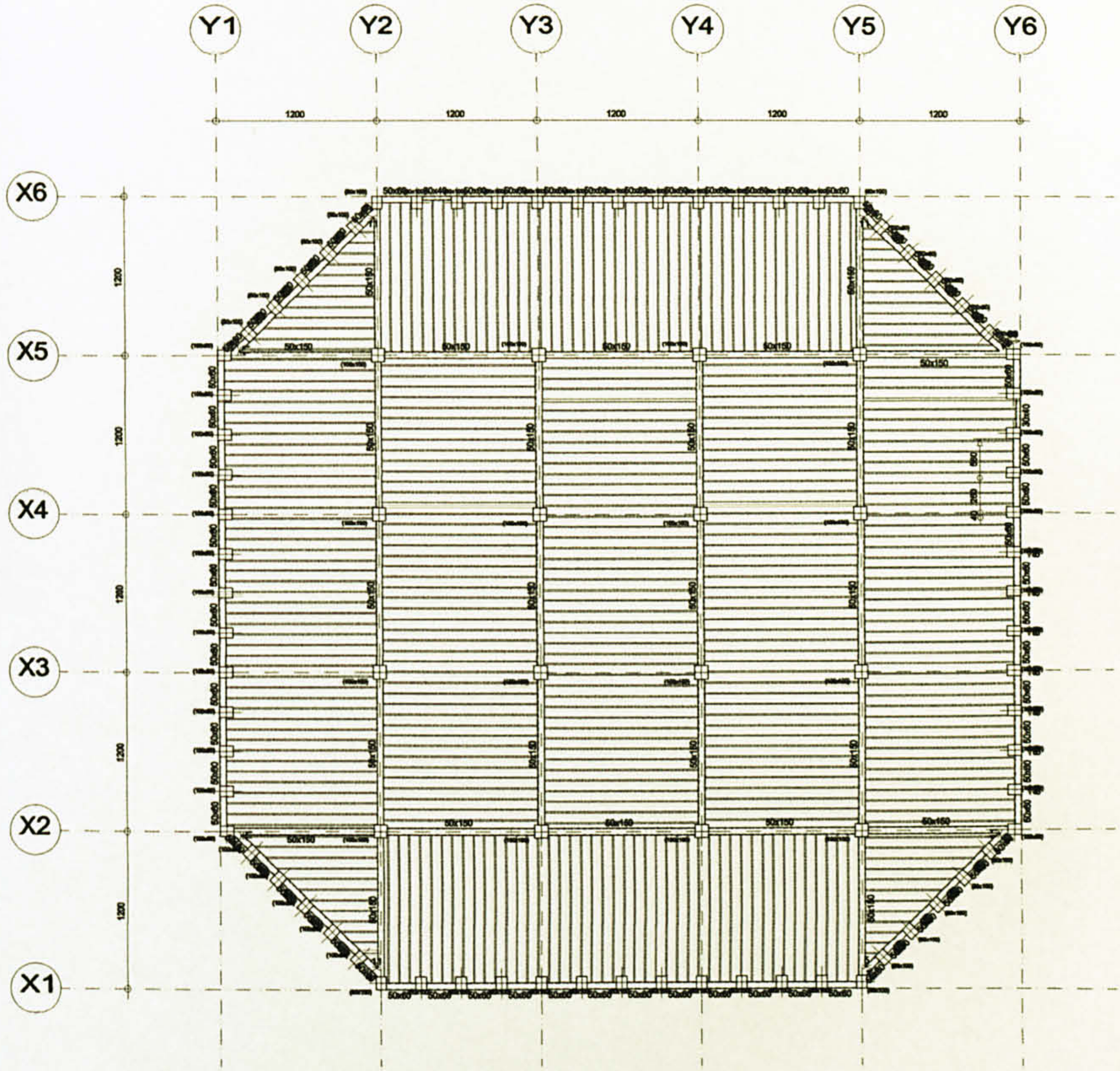

LEVEL 6 TO 10
PLAN VIEW
SCALE: 1:500



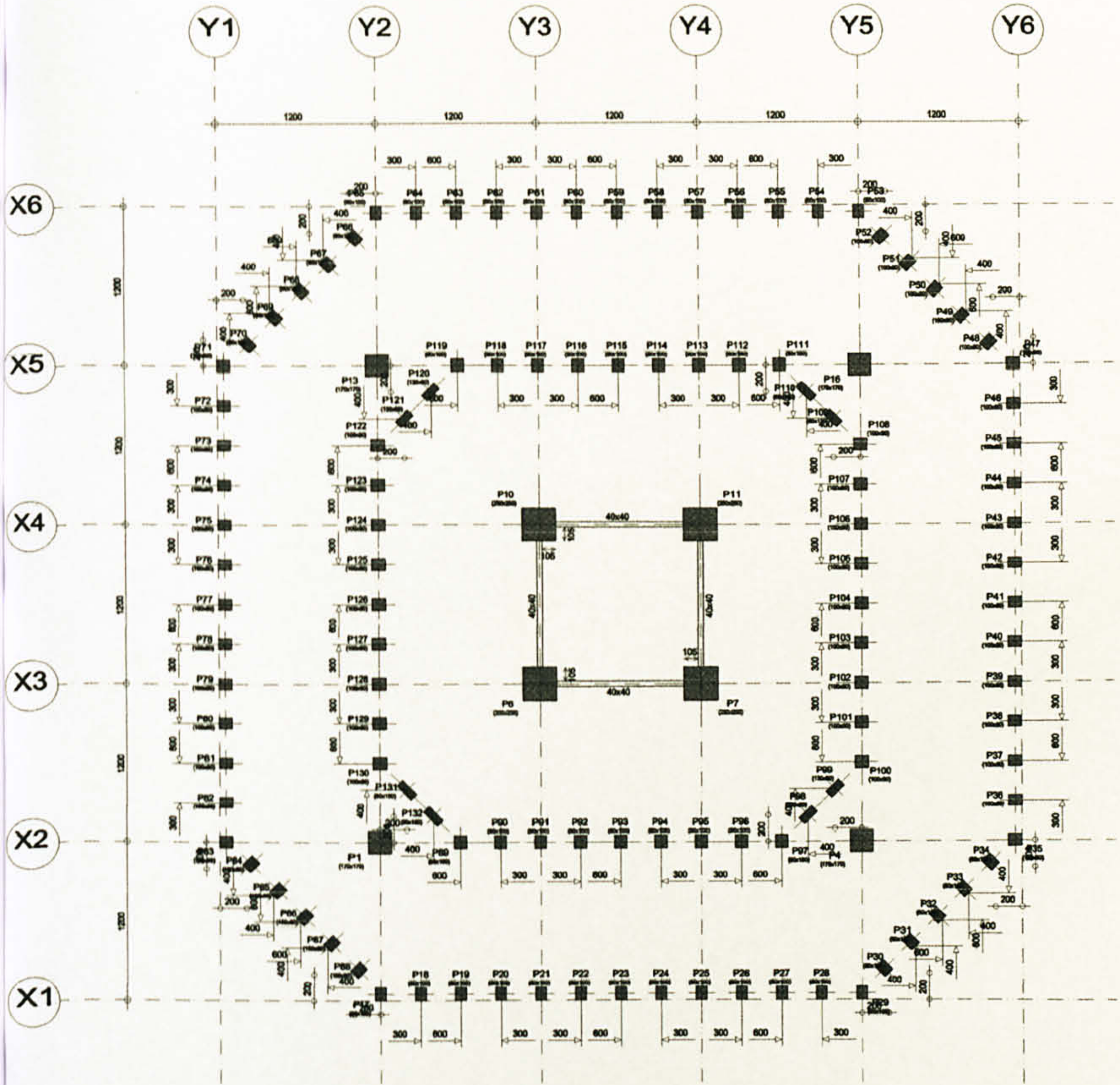

LEVEL 41 TO 45
PLAN VIEW
SCALE: 1:500



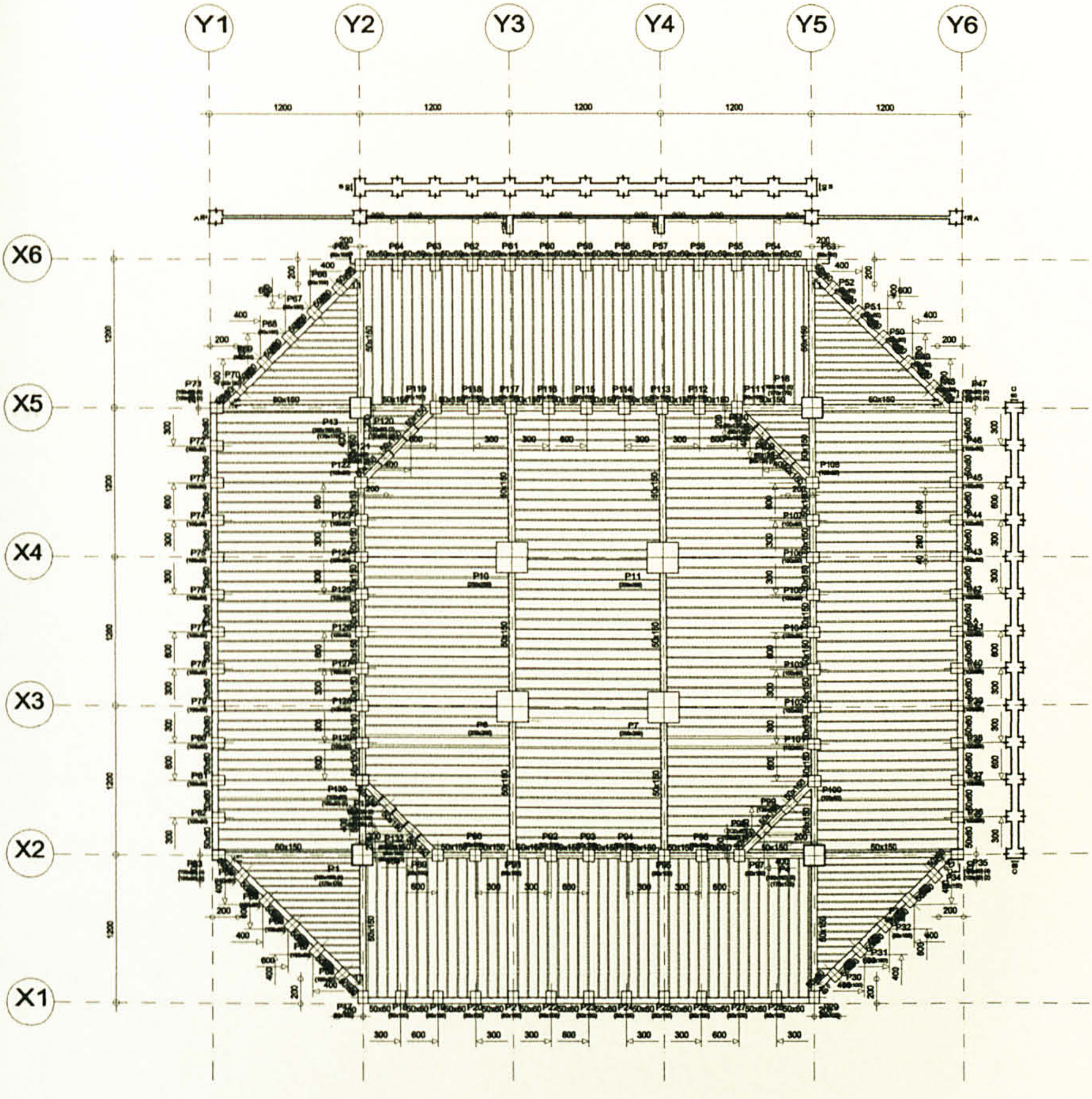

LEVEL 66 TO 70
PLAN VIEW
SCALE: 1:500



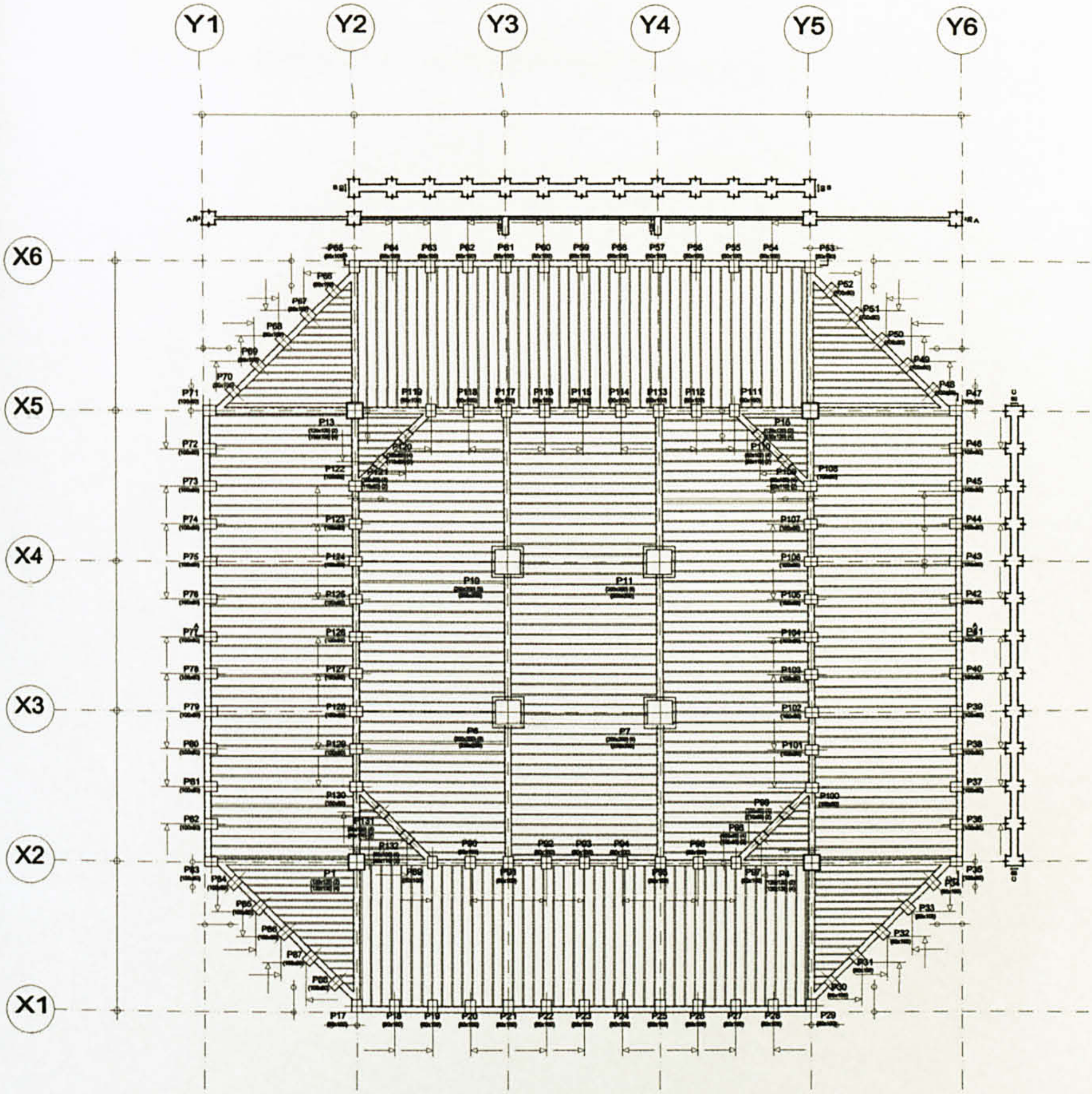

LEVEL 75
PLAN VIEW
SCALE: 1:500



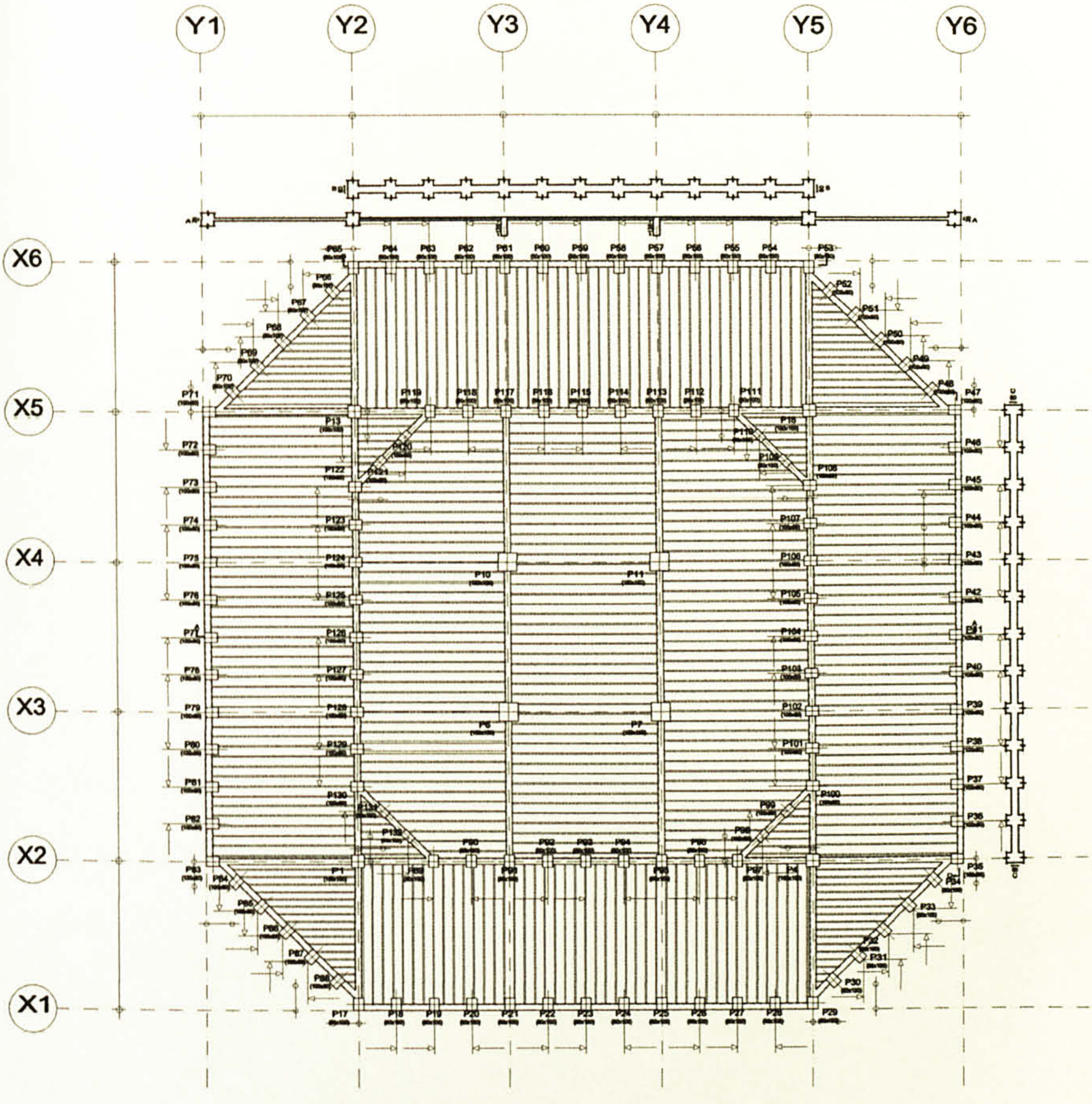

FOUNDATION
PLAN VIEW
SCALE: 1:500



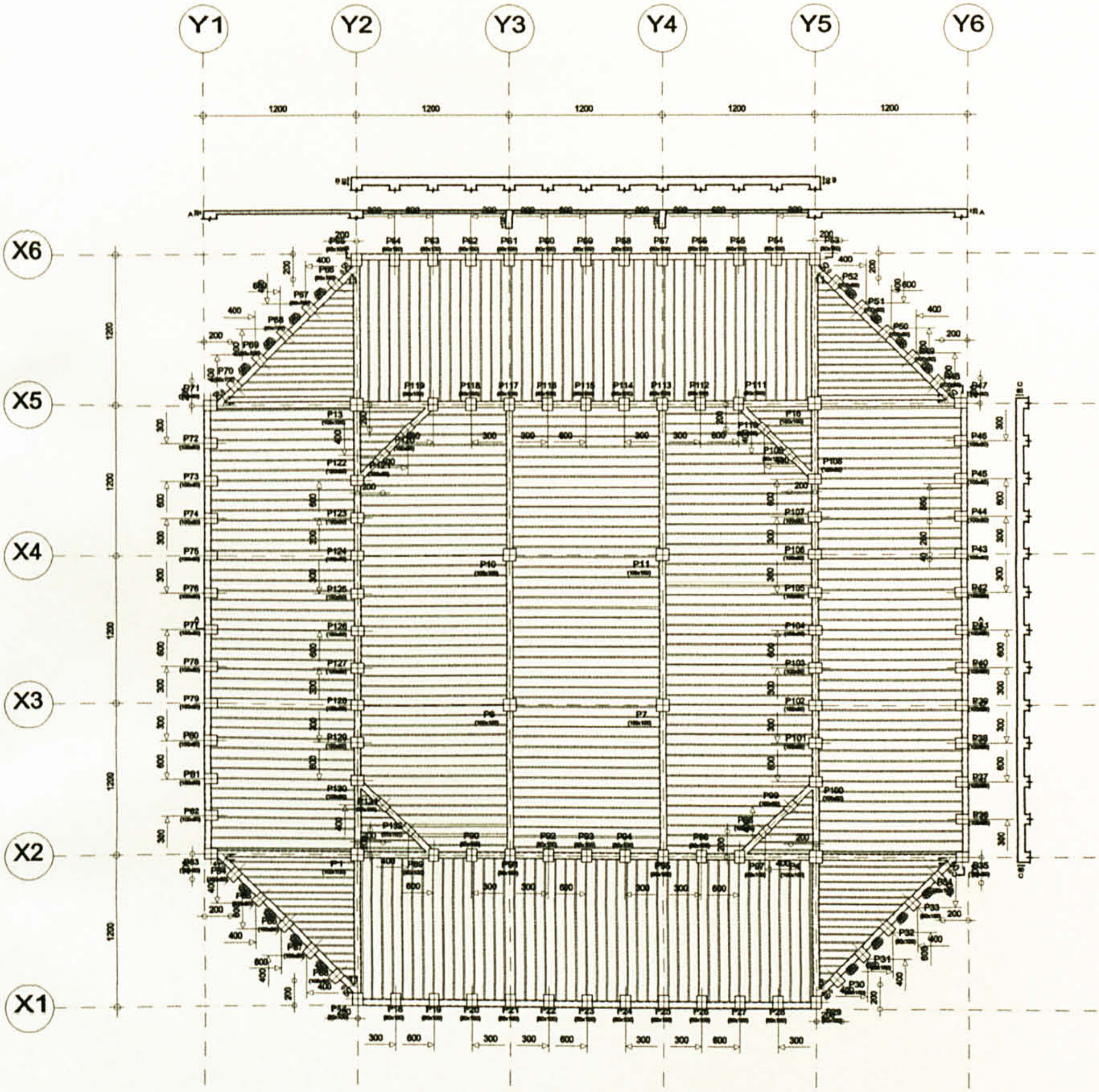

LEVEL 1 TO 5
PLAN VIEW
SCALE: 1:500




LEVEL 21 TO 25
PLAN VIEW
SCALE: 1:500




LEVEL 46 TO 59
PLAN VIEW
SCALE: 1:500




LEVEL 75

PLAN VIEW

SCALE: 1:500